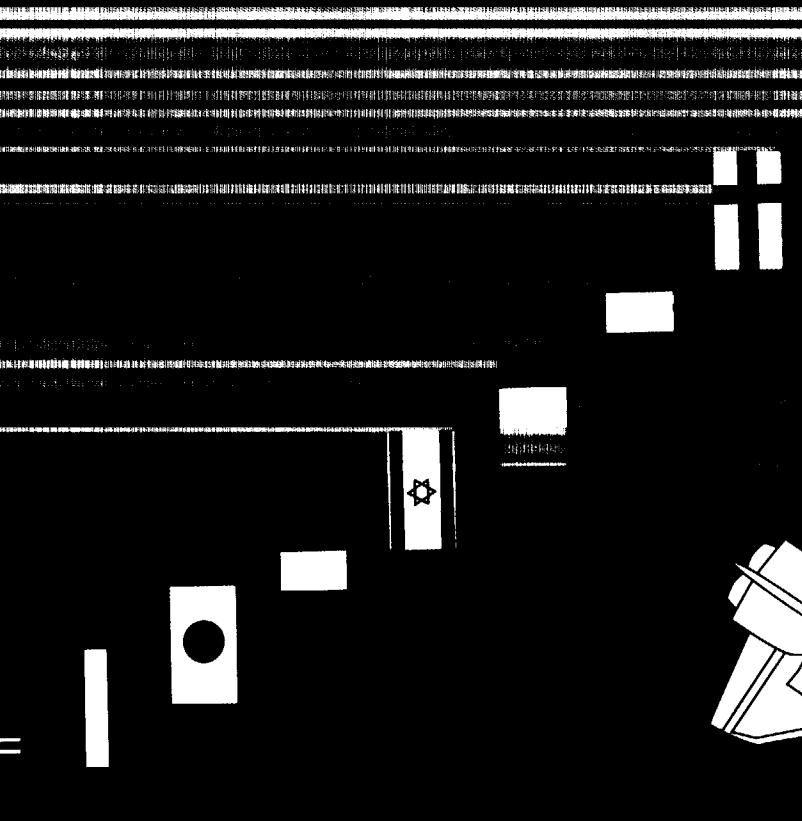


First International Microgravity Laboratory



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INTERNATIONAL MICROGRAVITY
LABORATORY (NASA) 59 p

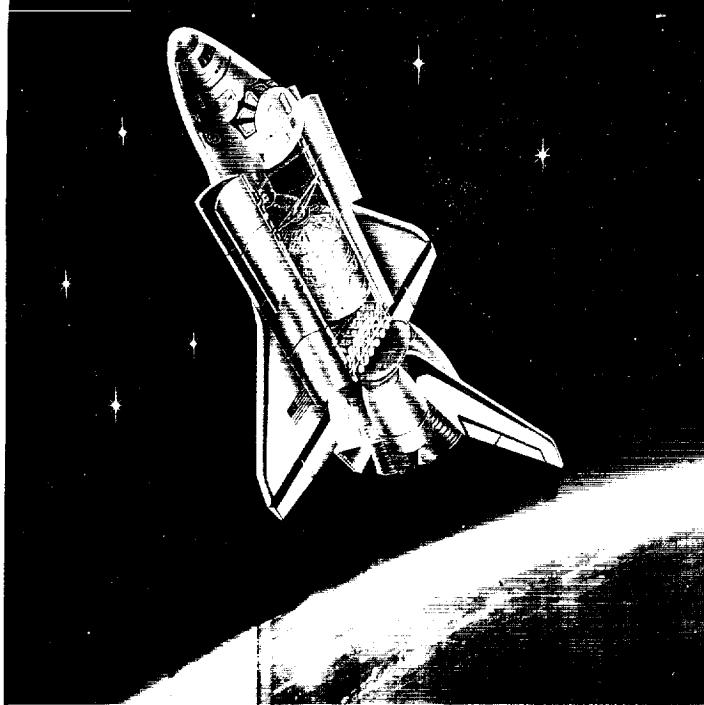
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First International Microgravity Laboratory

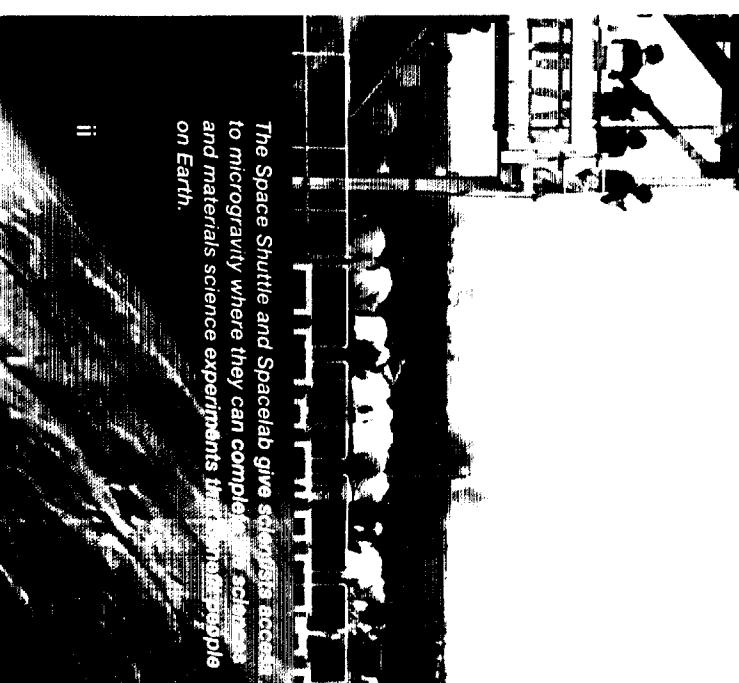
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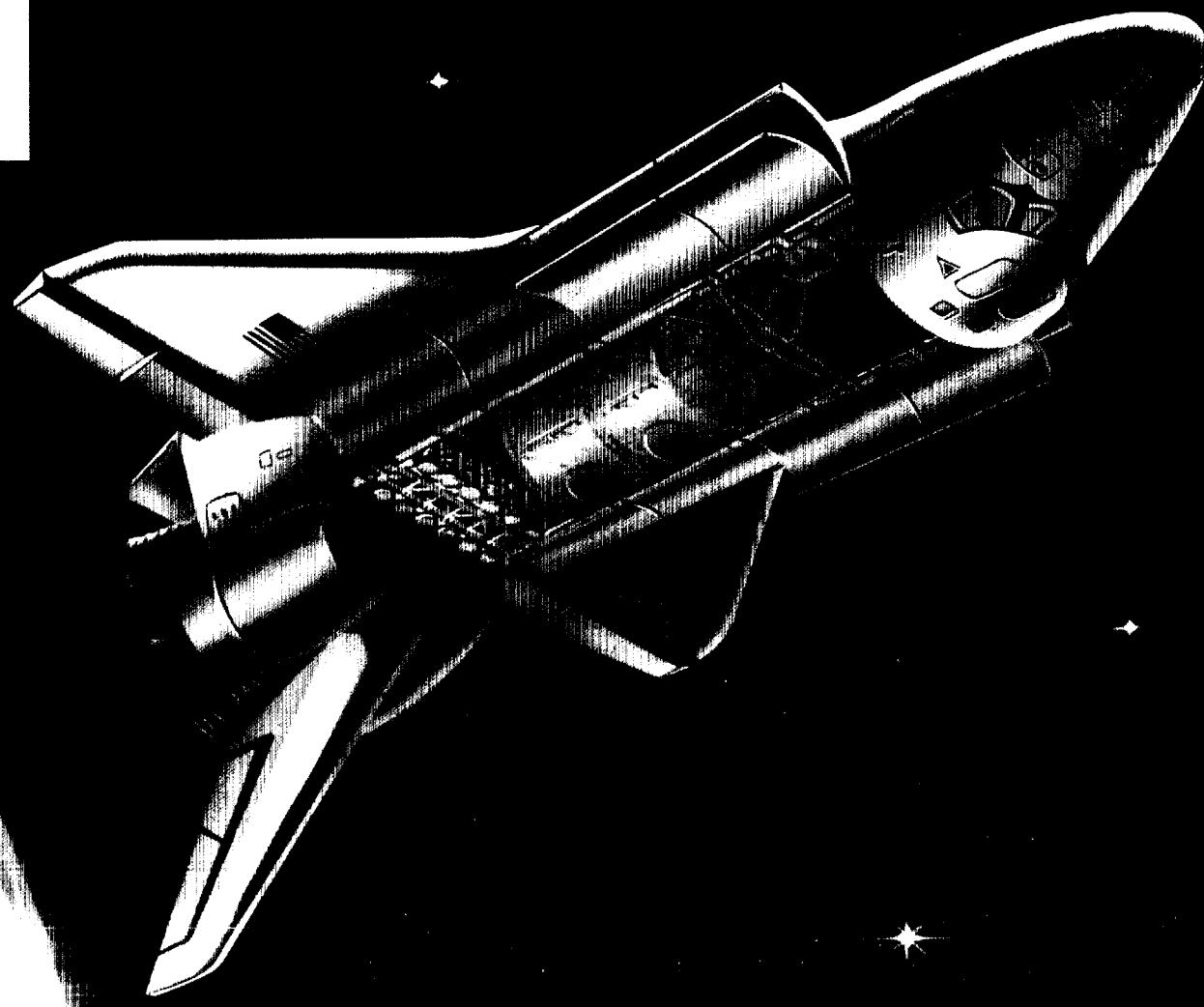
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National Aeronautics and
Space Administration



The Space Shuttle and Spacelab give scientists access to microgravity where they can complete scientific and materials science experiments that are not possible on Earth.



Shuttle Science in the 1990s

A laboratory inside the Space Shuttle is orbiting our planet. The spacecraft is positioned to experience the lowest gravity levels obtainable in near-Earth orbit. During the mission, scientist-crew members work in this International Microgravity Laboratory doing a variety of

investigations. They study life — from simple microorganisms to the complex bodies of humans. They make materials — from protein crystals that form the structure of life on Earth to electronic detectors used in high-tech devices. How does an environment virtually free of gravity affect the behavior of materials and life processes? Space crews will help answer these questions by making careful observations inside a microgravity laboratory.

Peering through a microscope, a scientist in space watches the rhythmic movement of a cell as it oscillates, moving itself slowly across a slide. Does the cell move differently in space where there is almost no gravity? Have its vibrations increased or decreased? Later, the biologist will preserve some bone cells exposed to microgravity. On Earth, the scientist's colleagues will examine the cells to see if they developed normally in space. Do they have defects similar to those found in the bones of some children? During the flight, hundreds of cells, microorganisms, and plants will be exposed to the weightlessness and radiation of space and then returned to Earth for in-depth analyses.

In the center of the space laboratory, crew members use elaborate equipment to study how humans adapt to microgravity. How do their sensory systems adjust to this place where there is no up nor down? Are changes in their inner ears, eyes, and nervous systems associated with space motion sickness?

Other parts of the laboratory house facilities for growing crystals and studying how basic fluid properties change in microgravity. Can we produce more perfect crystals in space where there is virtually no gravity to disturb formation processes? We can only learn by actually growing crystals in space and returning them to Earth for examination. Can some fluid properties be studied better in orbit? Again, only experiments in space can answer our questions.

The Space Shuttle's tail is pointed toward Earth to expose the International Microgravity Laboratory to the lowest possible gravity levels.

International Microgravity Laboratory 1 (IML-1), the first in a series of Shuttle flights dedicated to fundamental materials and life sciences research, will help answer some of our questions. As part of these National Aeronautics and Space Administration (NASA) missions, scientists from around the world have developed experiments that crew members will complete inside Spacelab, a laboratory carried aloft by the Shuttle.

IML-1 research began in ground-based laboratories where scientists studied the effects of gravity on living organisms and materials. Some investigators then did experiments that exposed their samples to a few seconds of microgravity aboard suborbital rockets and airplanes and in drop tubes. Investigators found evidence that materials and living organisms are influenced by microgravity, and they learned more about how gravity affects processes on Earth. Now, scientists are continuing their investigations aboard Spacelab over periods of several days.

IML-1 scientists are asking questions about the way gravity affects life and materials. Life sciences research will help reveal the role of gravity in shaping life as we know it and help us learn how living organisms

adapt to the microgravity environment. By studying the fundamental properties of materials processed in microgravity, investigators will characterize subtle reactions that are difficult to measure on Earth. They will also test facilities and experiment techniques to optimize similar hardware and operations for use aboard future IML missions and Space Station Freedom.

What we learn through the IML program will not only aid our space explorations but also is expected to improve life on Earth. If space experiments expand our knowledge about biological processes such as bone cell production of cartilage and inner ear sensitivity to gravity, we can apply what we learn to medical problems at home. Learning about the influence of gravity and other physical phenomena will be useful in producing materials on the ground. If protein crystals can be grown better in space, we may be able to define the structures of these basic components of life.

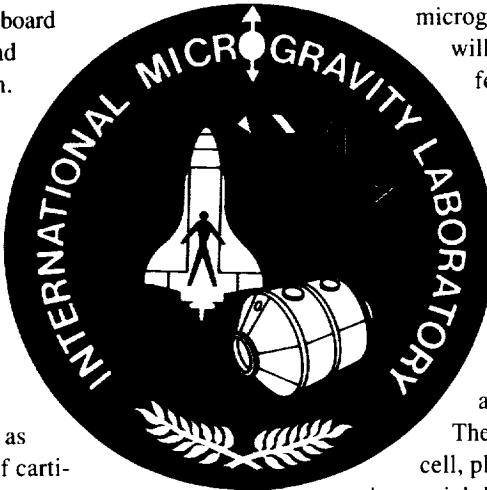
The International Microgravity Laboratory program gives a team of scientists from around the world access to a unique environment — one that is free from most of Earth's gravity.

What is Microgravity?

When the Space Shuttle is launched, enough horizontal velocity is generated to keep it from falling straight down; instead, it acquires a circular trajectory, or orbit, around Earth. At this altitude (usually around 200 miles), Earth's gravity is still very strong, but the spacecraft and its contents are free-falling back to Earth.

To understand what happens inside the Shuttle as it orbits Earth, think of a person standing in an elevator. If the person drops a coin, it lands on the elevator floor. But if the elevator cable breaks just as the coin is dropped, the elevator will fall at the same rate as the coin and the dropped coin will literally float. Einstein studied this phenomena and concluded that there is no physical difference between free-fall and the absence of gravity.

There are additional forces that influence an orbiting Shuttle and its contents, such as the drag of the atmosphere. These background influences are normally comparable to one-millionth of the Earth's gravity or 10^{-6} g, thus the term "microgravity."



The IML Program

A series of International Microgravity Laboratory missions will be launched over the next 10 years. Dedicated to the study of life and materials sciences in microgravity, these missions will explore how life forms adapt to weightlessness and investigate how materials behave when processed in space.

Both life and materials sciences benefit from the extended periods of microgravity available on the Shuttle.

The way an individual cell, plant, or animal behaves in a weightless environment reveals much about the influence of gravity on biological processes. Additionally, life scientists study what effects increased exposure to high-energy radiation during spaceflight has on living organisms. Gravity is also a dominant factor in materials processing on Earth, and as such, it masks the influence of more subtle phenomena, such as certain kinds of electromagnetic effects. In the absence of gravity, these other phenomena are unmasked, and it is possible to examine them.

Microgravity research programs benefit from the presence of scientists in space. Inside Spacelab, a fully equipped laboratory carried in the Shuttle payload bay, scientists can conduct experiments much as they do in laboratories on Earth: monitoring operations, changing experiment conditions, and refining investigations based on results.

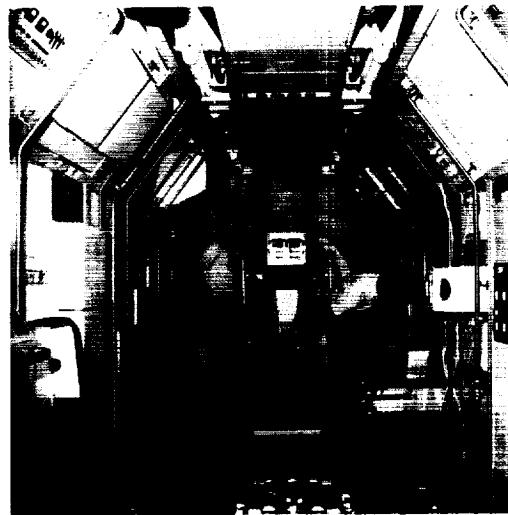
Because the life and materials sciences use different Spacelab resources, they are logically paired on the IML missions. Life sciences investigations generally require significant crew involvement, and crew members often participate as test subjects or operators. Materials science experiments quite often require large amounts of power. The IML missions capitalize on these complementary experiment requirements.

With the IML Program, NASA continues its 30-year tradition of initiating peaceful, cooperative space ventures with other countries. The 14-nation European Space Agency (ESA), the Canadian Space Agency (CSA), the French National Center for Space Studies (CNES), the German

Space Agency and the German Aerospace Research Establishment (DARA/DLR), and the National Space Development Agency of Japan (NASDA) are NASA's partners in developing hardware and experiments for IML missions.

International cooperation during the IML missions enables participating nations to attain mutually beneficial goals. NASA provides mission management, payload integration, and Shuttle transportation to and from orbit. Other space agencies provide hardware that their own scientists and American scientists use. Joint use of facilities in the large international inventory of flight research equipment reduces the cost of space experimentation for each agency. Investigators also share data and samples so that scientific return is multiplied.

As scientists from around the world learn more about microgravity and how to exploit that environment, they will gain the experience needed to design investigations and hardware that yield progressively greater returns. Advanced experiments will be developed for Space Station Freedom, and technologies necessary to establish a permanent human presence in space will be tested. Through the IML missions, working relationships, confidence in international partners, and a cooperative spirit will be fostered. The program will lay the groundwork for broader international partnerships and scientific alliances that may continue into the space station era.



Spacelab is a fully equipped laboratory that fits in the payload bay of the Space Shuttle. Here, IML-1 crew members practice conducting experiments on the ground in a mockup of Spacelab.

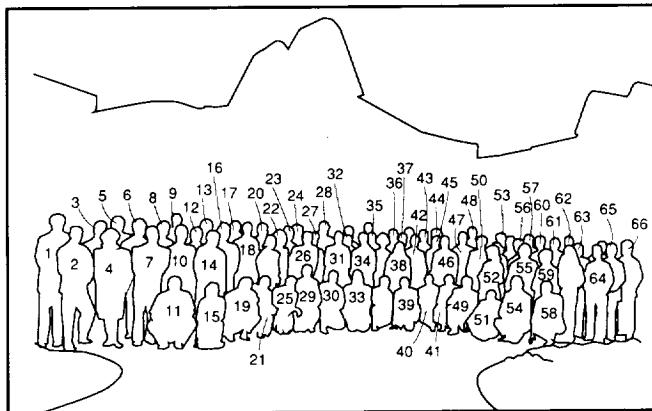


IML-1 Mission Management

Preflight

The IML Program is sponsored by NASA's Office of Space Science and Applications and directed by the Flight Systems Division at NASA Headquarters in Washington, D.C. At this level, the Program Manager and Program Scientist define the program and science goals, select experiments, and fund payload hardware development, investigator teams, and publication of the missions' scientific results.

The IML-1 mission is an integral part of a comprehensive international program to complete life and materials sciences experiments in space. To maximize the science information gleaned during the mission, many years are spent in careful preparation and training. A team of NASA managers, scientists, engineers, technicians, and support contractors work together to plan, organize, develop, and implement each IML mission. The NASA Marshall Space Flight Center in Huntsville, Alabama, manages the IML flights.

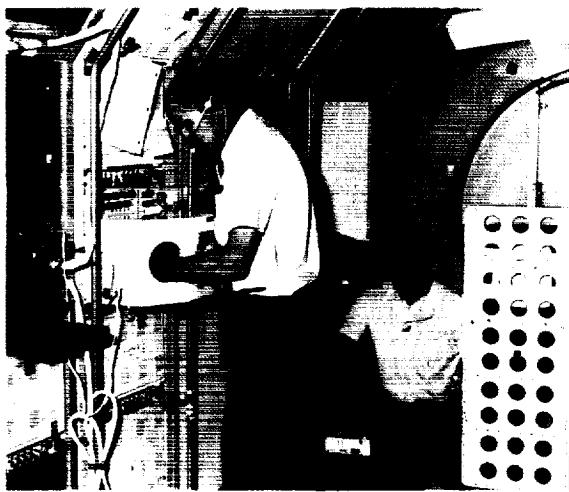


The Mission Manager establishes the mission guidelines in light of the overall IML-1 mission goals, manages technical progress as the mission develops, allocates human and financial resources, oversees the mission's payload integration and operations, and coordinates the activities of NASA and the other space agencies participating in the mission. Assisted by a management team, the Mission Manager also supervises payload crew and ground support team training and devises a very detailed and specific mission timeline, the minute-by-minute master schedule for in-flight activities. The Mission Scientist acts as the liaison between the science investigators and the Mission Manager to guarantee that the mission science objectives are met.

Principal investigators also play an important role in developing the IML-1 mission. They form an Investigator Working

The Investigator Working Group, which is made up of scientists and engineers from around the world, meets periodically to evaluate IML-1 science concerns.

1. Heibert Martinides
2. Peter Wing
3. Alain Magnon
4. Hildegarde Binck
5. Byron Lichtenberg
6. Heinz Oser
7. Alain Gonfalone
8. Wayne Richie
9. Mark Tcherneshoff
10. Angel Plaza
11. Augusto Cogoli
12. Scott Wood
13. Robert McBrayer
14. Maria Roth
15. Mary Cleave
16. Claude Brilouet
17. Kent Lasley
18. Mill Reschke
19. Horst-Dieter Menningmann
20. Ken Money
21. Peter Genzel
22. Carol Otale
23. Jacobos-Paul Veldhuijzen
24. Gilbert Gassel
25. Ulf Merbold
26. Robert Cadoret
27. Geertje Ubbels
28. Conrad Woldringh
29. Robert Snyder
30. Norman Thagard
31. Guy Ralle
32. René Tixador
33. Terry Curry
34. Bill Paloski
35. Wolfgang Briegleb
36. Enno Brinkmann
37. Ronald White
38. Ingrid Block
39. Ravi Lal
40. Chuck Winget
41. Roberta Bondar
42. Teun Michels
43. Michael Cork
44. Klaus Schmidt
45. Greg Brixtry
46. Sandy Alexander
47. Alan Brown
48. Richard DeLombard
49. Dave Chapman
50. Lodewijk van den Berg
51. David Heathcote
52. Carol Verrett
53. Roger Crouch
54. Hermon Hight
55. Tina Melton
56. Ronald Schaefer
57. Wayne Bart
58. Ole Rasmussen
59. Sally Robinson
60. Greg Nelson
61. Carlo Bruschi
62. Joe Brooks
63. Bruce Aikenhead
64. Clint Smith
65. Hans Hamacher
66. John Frazier



The science crew members practice experiments inside a mockup with replicas of the IML-1 facilities.

Group which convenes periodically to discuss progress in meeting the science objectives and requirements of the mission. Through the Mission Scientist, who chairs the group, they advise the mission management team on science issues. They design investigations to yield the greatest scientific returns; match experiment requirements to Spacelab power, data collection, and size capabilities; collaborate with hardware and software developers; and help select and train the payload crew. (The experiment descriptions that follow detail the science objectives for the IML-1 mission and supplementary science that will be done as time permits.)

The mission management team is responsible for training the crew in science operations and preparing the principal investigator teams for their roles in the ground control center during the mission. Some of the training is done in the principal investigator's laboratories so that the crew understand the concept, hardware, and operation of the scientist's experiment. Then, experiments are practiced inside a crew training mockup with high-fidelity replicas of all the flight experiments. Everyone involved with the mission participates in simulations to practice planned procedures, communications, and problem solving.

While the Marshall Space Flight Center manages the IML-1 payload operations, other NASA centers and foreign space agencies are crucial to the IML-1 mission.

The Space Transportation System is prepared and launched at the Kennedy Space Center in Cape Canaveral, Florida. Using a blueprint designed by the Marshall mission management team, Kennedy personnel install the experiments into Spacelab and the orbiter middeck and load Spacelab into the Shuttle payload bay. The Mission Control Center at Johnson Space Center, Houston, Texas, controls the Shuttle flight from shortly after launch to landing, continually directing and monitoring the progress of orbiter flight operations. Goddard Space Flight Center in Greenbelt, Maryland, maintains the ground-to-Shuttle and Shuttle-to-ground communications through a network of satellites and ground-based relay stations and records data from experiments.

On-Orbit

During the mission, the management team works in the Payload Operations Control Center at the Marshall Space Flight Center. In this area, digital data, video, and voice communications from the Shuttle keep the team apprised of science operations so that they can monitor and direct Spacelab operations. The principal investigators also use this control center as their operations base during IML-1. Through its communications network, they follow the progress of their experiments and instruct the crew or send computer commands directly to Spacelab to make adjustments to experiment parameters, hardware, or protocols.

IML-1 Management Team

Mission Manager
Mr. Robert O. McBrayer
MSFC

Asst. Mission Manager
Mr. John L. Frazier
MSFC

Program Manager
Mr. R. Wayne Richie
NASA Headquarters

Program Scientist
Dr. Ronald J. White
NASA Headquarters

Mission Scientist
Dr. Robert S. Snyder
MSFC

Asst. Mission Scientist
Ms. Teresa Y. Miller
MSFC

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When the Shuttle obtains the operational orbit, the payload crew members open the airlock and float from the Shuttle middeck through a tunnel into Spacelab. Soon, they begin to set up equipment and turn on experiment facilities. Specimens and containers are transferred from middeck stowage to the laboratory where they are put in specific experiment facilities.

For the first 2 days of the mission, the crew are busy doing life sciences experiments that will reveal how their bodies adapt to living in space. They also put some experiment samples, such as plants, cells, and crystals into plant growth chambers, incubators, and crystal growth chambers. The crew concentrate mainly on investigations in which they serve as test subjects, such as experiments that study the inner ear, eyes, and nervous system. The middle of the mission is dedicated primarily to materials processing research that requires a quiet environment with as little movement as possible. During this quiescent period, the crew insert crystals and other samples into furnaces and monitor them during critical growth phases. Under these conditions, crystals can develop undisturbed by vibrations that could cause imperfections. Experiments also proceed with plants, cells, and other biological specimens. Investigations are checked periodically and, if necessary, the specimens are replaced and preserved for ground-based analysis. The crew use both voice and video links to consult the principal investigators on the ground during critical operations.

The last 2 days are spent completing investigations and doing other experiments. The crew are busy taking final physiological readings to show how they have adapted to space. On the last day, the crew disconnect equipment, transfer some of the specimens and containers to the middeck stowage, and secure them for landing.

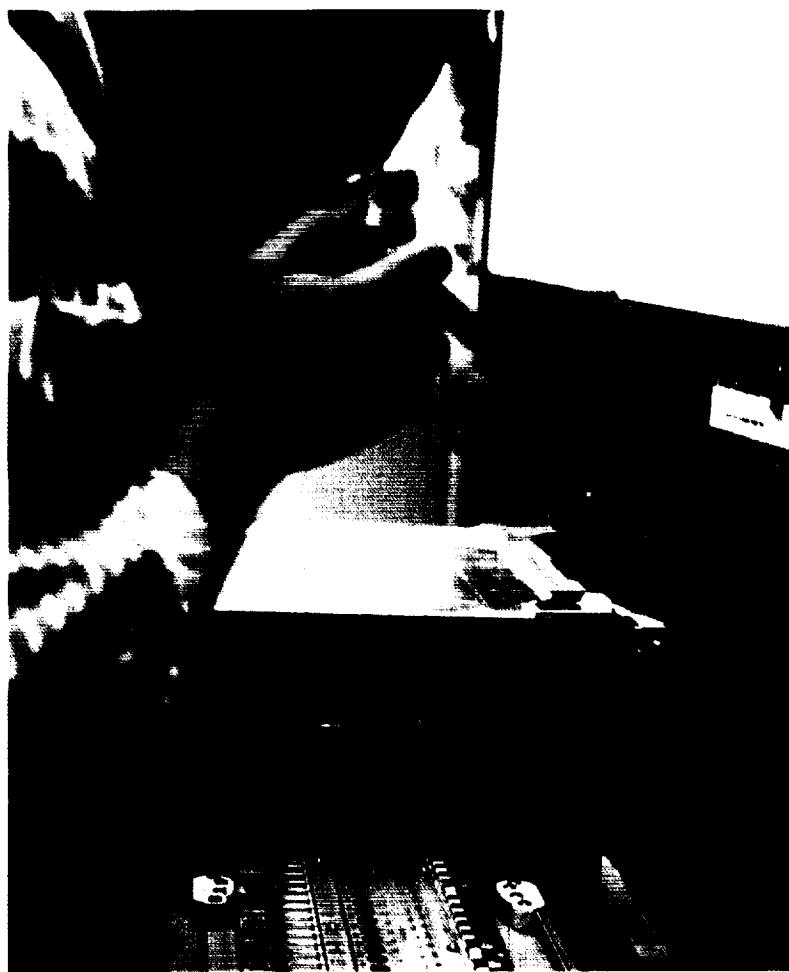
Postflight

The Mission Manager works with the scientists to ensure that they get all the data necessary for thorough scientific studies. Animals, plants, films, tapes, crystals, experiment samples, and other objects are removed immediately after landing for postflight evaluation. Later, experiment equipment is returned to the hardware developer for potential reuse.

After the mission, a considerable amount of data is available for scientific analysis. Most information automatically goes from the Shuttle to the Spacelab

Processing Facility at Goddard Space Flight Center in Greenbelt, Maryland. At this facility, incoming data are recorded, separated, and organized according to experiment before being sent to the investigators. The investigators obtain computer tapes, voice recordings, and video tapes made during the mission from Goddard.

Complete analysis of all the data acquired during the mission may take from a few months to several years. This information will be used to develop new experiments for future IML missions.



After the Shuttle lands, experiment samples are returned to the principal investigators for analysis. Here, a scientist photographs a tray of samples he has pulled from the Protein Crystal Growth experiment flown on STS-26.

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An astronaut removes a small container of lentil seedlings from a Spacelab rack, moves it to an enclosure where it can be handled safely, and begins to examine the container's contents.

Through a satellite communications link to a scientist on Earth, the payload specialist reports a preliminary finding.

► "I've just removed a growth chamber. Some of the seeds have sprouted, and I'm preparing to photograph them."

In a control room on the ground, the other scientist watches the *in-flight* procedures on a television screen.

► "Do you see any indication of directional growth?"

► "Not in this sample," the payload specialist replies. "The roots are growing in all directions."

► "What about the plants in the centrifuge?"

► "They seem to have reoriented in the direction of the centrifugal force."

► "Fine. That's just what we'd expected."

After putting another chamber of seedlings on the centrifuge, the payload specialist unpacks the Spacelab video camera and begins filming another crew member who is writing at a moveable workstation attached to a Spacelab railing. This mission specialist is filling out a report on an experiment just completed and is evaluating three devices used to move a computer cursor.

The videotape records the astronaut's posture and the location of the workstation and is going to be used, along with the payload crew's evaluations, to design efficient and comfortable work areas for future Shuttle flights and the space station.

When the report is done, these two crew members go off duty, and another payload specialist and mission specialist begin their shift. They first open up a sled attached to the Spacelab floor. This sliding bench is used in experiments that probe the workings of the inner ear. The first person to be tested floats over to the sled to be strapped into position.

► "OK, now hand me the electrodes for my leg, please," the test subject asks the other crew member, who is working at a computer beside the sled. When the electrodes are in place, the subject inserts a pair of ear plugs and puts on a blindfold.

► "We're ready to begin the first test," the operator reports to the science team on the ground. "I'm keying in the sled velocity."

As the sled begins to move, small electric impulses are applied to the test subject's leg through the electrodes, and the computer records and stores the leg's responses.

After the sled has made several trips back and forth across the railings, the operator stops the sled, unlatches the seat from its runners, and gently maneuvers the sled and subject to a new position. Once the subject is securely in place, the same test is repeated. When the Shuttle returns to Earth, scientists will analyze these data to see whether organs in the inner ear that normally respond to accelerations and thus help a person maintain balance can continue to perform that function in space.

Later during this shift, the mission specialist is scheduled to photograph an experiment that studies how biological materials can be separated in space. Meanwhile, the payload specialist is setting up more camera equipment to make stereo pictures of the tape attached to the mission specialist's back. These pictures will tell scientists who are studying back pain how weightlessness affects the length and shape of the spine.

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IML-1 Life Sciences Experiments

The importance of conducting life sciences investigations in space cannot be overestimated. The plant growth experiment, for example, is one of the IML-1 studies developed to determine the responses of plants and animals to the space environment. Before we spend long periods in orbit or make extended journeys in space, such as months-long tours of duty aboard the space station or years-long missions to other parts of the solar system, we must know how life forms that evolved on Earth are affected by the reduced gravity and increased radiation doses encountered in space. Such investigations are crucial if humans are to live and work in space safely and effectively. We know that exposure to microgravity causes the human body to function in ways that are appropriate for living in a low-gravity environment but may

be dysfunctional for living on Earth; that, in orbit, astronauts must have protection from damaging, even lethal, radiation; and that the responses of animals and plants during spaceflight differ from their behaviors on the ground.

The IML-1 investigations will build on what is already known about adaptation to space and add information needed to develop measures that enhance the quality of life in space and counteract potentially harmful physiological responses to microgravity. Many such measures have been used during the 30 years that the United States has been sending vehicles and people into space. For instance, the Space Shuttle has special radiation shields to protect crews from high-energy radiation, and exercise and nutrition programs are being devised to alleviate some of the detrimental effects of low-gravity on the body.

The IML-1 life sciences investigations continue the exploration of how conditions in space affect terrestrial life forms. To examine the adaptation of the human body to a gravity-free environment, the payload crew members conduct experiments on themselves. From these studies, scientists learn more about the reactions of the vestibular, nervous,

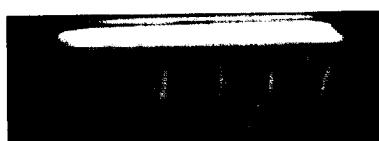
circulatory, skeletal, muscle, and metabolic systems to weightlessness. With other animals and plants, investigators define the effects of microgravity and radiation on growth patterns, genetic material, bone development, cell differentiation and reproduction, and the effectiveness of antibiotics. They monitor radiation levels to identify potential damage to living organisms, and they design convenient and comfortable laboratory equipment for the crew to use.



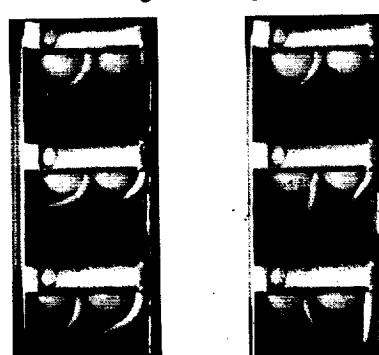
IML-1 investigations into how the human body adapts to weightlessness must be conducted before people can safely journey into space for long periods.



μg



1g centrifuge



1g for 3h

During Spacelab D1, scientists studied how gravity affected the growth of lentil roots. On IML-1, biologists continue their studies of lentils and several other plants.

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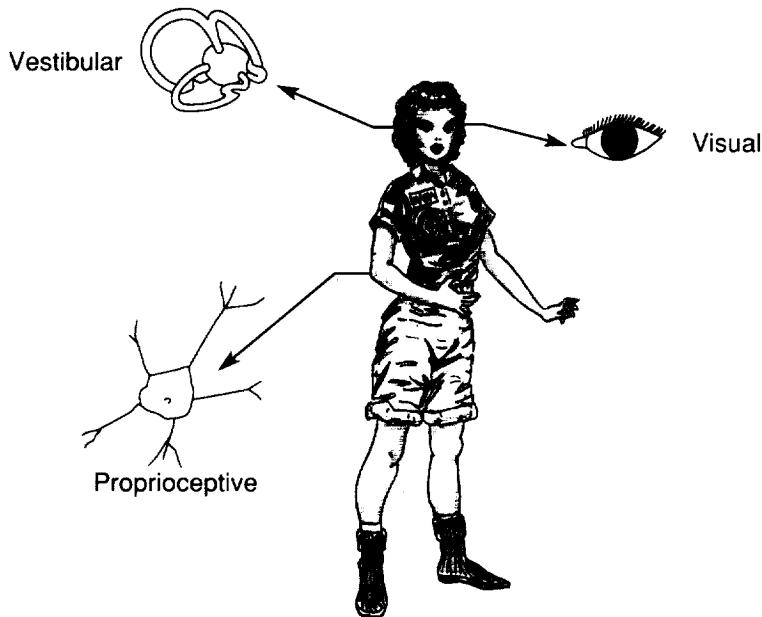
Life Sciences Experiment Hardware

Biorack	ESA
Biostack	DLR
Gravitational Plant Physiology Facility	NASA
Mental Workload and Performance Experiment	NASA
Microgravity Vestibular Investigations	NASA
Radiation Monitoring Container Device	NASDA
Space Physiology Experiments	CSA

The following descriptions detail life sciences experiments that have been scheduled for the IML-1 mission and supplementary science that will be done if time permits.

Microgravity Vestibular Investigations

- Provided by: NASA
- Principal Investigator: Dr. Millard F. Reschke
- NASA Johnson Space Center, Houston, Texas, USA



Because the human brain translates information from the eyes, organs in the inner ears, and certain cells in the skin and other body tissues, we can maintain our balance, focus our eyes on an object while our heads turn, and visually track a moving target.

IML-1 science team members test a rotating chair, which stimulates the test subject's visual and vestibular systems. The chair's motion is controlled by a second crew member using a computer.

People depend on the interaction of virtually every sensory system in the body for spatial orientation. Our perceptions of location and position are a result of the brain's ability to integrate visual and auditory signals with vestibular input (from gravity- and motion-detecting organs in the inner ear) and proprioceptive information (from motion, pressure, and temperature sensors in the tendons, muscles, joints, and skin). A person's expectations about the direction and speed of a chosen movement complement this system.

When environmental conditions change so that the body receives new stimuli, the nervous system responds by interpreting the incoming sensory information differently, though appropriately. In gravity, for instance, interaction among the sensory, motor, and perceptual systems enables the control of eye, head, and body motions relative to Earth. In space, the free-fall environment of an orbiting spacecraft requires that the body adapt to the virtual absence of gravity. Input that the brain receives from the sensors stimulated by gravity is changed, prompting the nervous system to develop a new interpretation of the available data. Until this occurs, crew members may feel disoriented or experience space motion sickness, which often reduces their efficiency. Almost two-thirds of all veteran astronauts, in fact, have reported symptoms of space motion sickness: faintness, sweating, dizziness, nausea, or vomiting.

Although adaptive changes are appropriate and beneficial in space, upon return to Earth, an astronaut may again be disoriented. The nervous system must again reevaluate sensory input so that perception, motor control, and movement are suited for Earth's gravity.

The Microgravity Vestibular Investigations examine the effects of orbital flight on the human orientation system to obtain a better understanding of the mechanisms of adaptation to weightlessness. By provoking interactions among the vestibular, visual, and proprioceptive systems and then measuring the perceptual and sensorimotor reactions, scientists can study changes that are integral to the adaptive process.



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The Vestibular System

When a cat is dropped upside down, it lands right-side-up. When a newborn infant is tilted backward, its eyes roll downward so that its gaze remains fixed. If the head is turned from side to side while a person is reading, the print stands still. Each of these responses is basically reflexive in nature. The body compensates for a disturbance to balance or orientation, and each response is controlled, in part, by a sensory apparatus in the cavities (vestibules) of the inner ear.

The vestibular system stabilizes gaze and ensures clear vision during head movements. Because head movements can be fast, the visual system, encumbered by relatively slow processing in the retina of the eye, cannot act rapidly enough to produce compensatory eye movements that would maintain steady images on the retina. The vestibulo-ocular reflex, which depends upon the motion sensors of the inner ear (semicircular canals and otolith receptors), produces prompt eye movements that compensate for head rotations. For example, a horizontal rotation of the head to the right produces an equal eye movement in the eye socket to the left so that the gaze does not waver and images do not move on the retina.

The vestibulo-ocular reflex cannot maintain an image on the retina during sustained rotation, however, and another means of image stabilization is needed to supplement the fading vestibular response. The optokinetic system, which maintains compensatory eye movements during sustained rotation when the inner ear signals decline, serves this function.

The Microgravity Vestibular Investigations use equipment specially designed or modified for Spacelab. A rotating/oscillating chair system tests the crew member's visual and vestibular responses to head and body movements. The chair's position on the rotator/oscillator can be changed so that a crew member is seated upright and turns around the yaw axis (from left to right), lies on one side and moves around the pitch axis (backward and forward), or lies on the back and moves around the roll axis (head over heels).

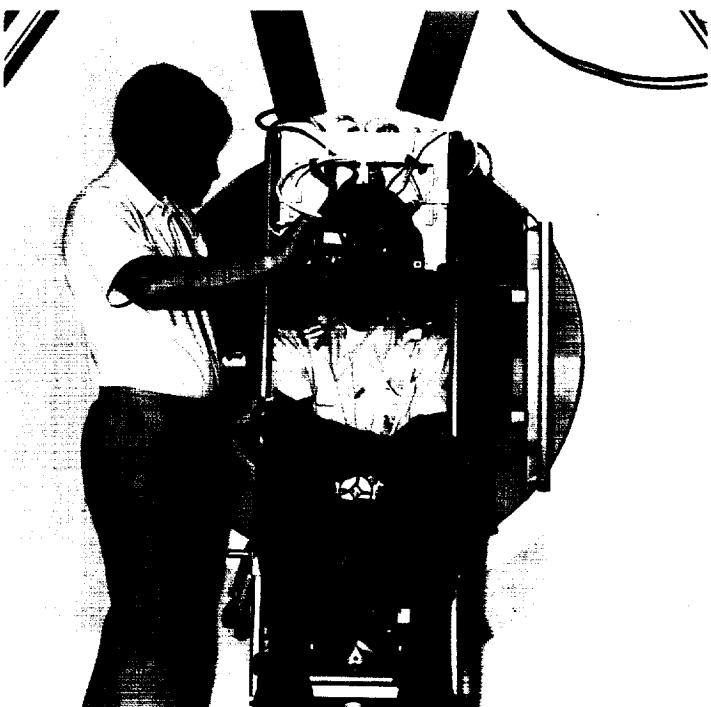
The chair system also has three velocity patterns: sinusoidal (traveling predictably back and forth over the same distance at a constant speed), pseudorandom (moving back and forth over varying distances and at changing velocities), and stepped (beginning and stopping suddenly). The system is located in the Spacelab rear center aisle and is controlled by a crew member using a computer.

Each crew member being tested wears a helmet assembly with accelerometers to measure head movements and two moveable visors that fit over the left and right eyes independently. Two helmet modules can be mounted on the visors. The camera module contains a video camera that records vertical, horizontal, and torsional eye movements. (Torsional eye movements are produced when the head rotates in the roll axis.) On one eye, the subject wears an opaque contact lens marked with two white dots. The lens shuts out light, and the dots provide a reference to determine how much the eye torsions in its socket when the subject is rotated. The video camera recordings of the movement of the dots on the lens measure eye movements. The optokinetic stimulus module contains a motor-driven, black-and-red checkerboard pattern that moves at variable speeds and directions (horizontal, vertical, and oblique) to provide a moving visual display in front of the eye. In addition, when free-floating, the subject wears a pair of binocular optokinetic stimulus goggles. The goggles contain a motor-driven, black-and-red-striped pattern that also moves at variable speeds and directions.

The helmet interface box, an electronics package mounted on the rotator/chair assembly, sends experiment sensor data to the experiment control and display interface located in a Spacelab rack. This equipment sends control signals to the helmet interface box, displays data for the experiment operator, and has a data downlink through Spacelab equipment to scientists on the ground.

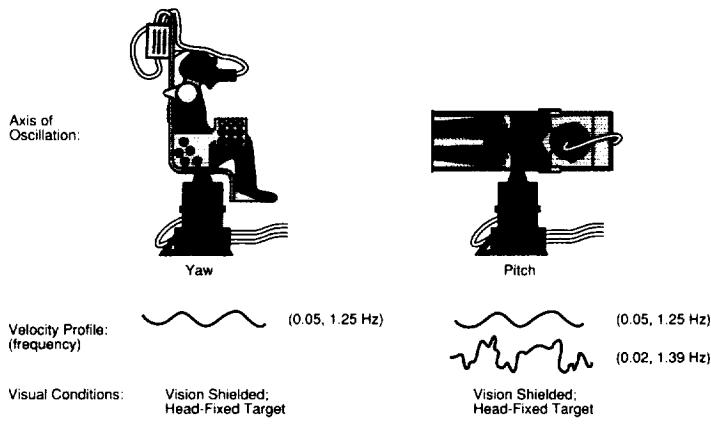
At least three times each during the IML-1 mission, crew members perform the experiments that make up the Microgravity Vestibular Investigations. Under each experiment condition, nystagmus (an involuntary spastic motion of the eyeball) is recorded by the video camera and by an electro-oculographic technique that records eye movement. Electrodes placed at the outer corner of each eye respond to horizontal eye movements, and others placed above and below one eye sense vertical eye movements.

Measurements are made early in flight to observe initial vestibular changes. Additional tests at the middle and end of the mission permit investigators to observe adaptation. Postflight testing, beginning as soon as possible after landing and continuing over a long period, lets scientists study aftereffects and assess the time required for the vestibular system to return to its preflight function.

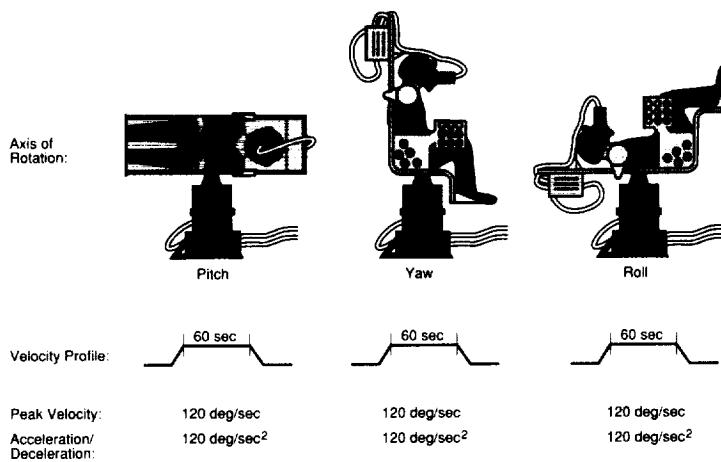


A special helmet records the subject's eye movements while the chair is rotating. Two different modules can be attached to the helmet's individual visors.

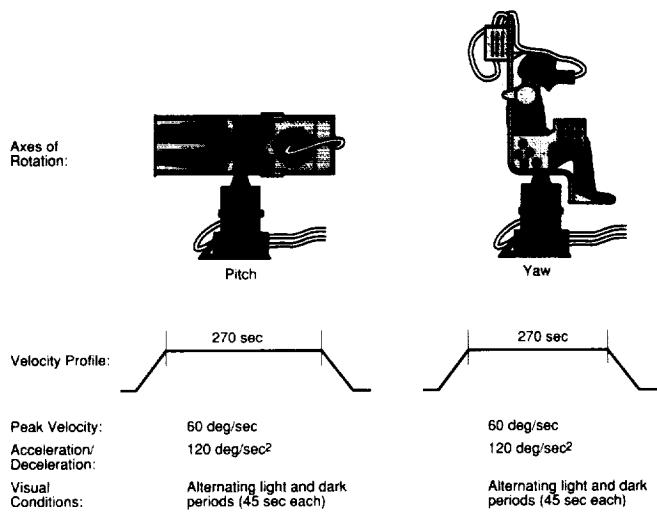
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**Experiment conditions:
Suppression of the Vestibulo-Ocular Reflex**



Experiment conditions: Per- and Post-Rotatory Nystagmus



Experiment conditions: Optokinetic Responses

Suppression of the Vestibulo-Ocular Reflex

When the head is turned while looking at a spot on the wall, the eyes move exactly opposite the direction that the head is moving. These eye movements are indicative of the vestibulo-ocular reflex. When a person spins around while looking at a finger held in front of the face, the vestibulo-ocular reflex is suppressed, allowing the eyes to fix on a target that moves in relation to its background but not relative to the head.

The purposes of this experiment are to test a subject's ability to suppress the vestibulo-ocular reflex and to determine whether this ability is affected by orbital flight. The first part of the study elicits the vestibulo-ocular reflex by rotating the subject sinusoidally in total darkness about the pitch axis and pseudorandomly about the yaw axis. During rotation, the subject fixates on an imaginary target in the distance. The second segment suppresses the reflex as the subject focuses on a head-fixed target light while rotating in the dark.

Per- and Post-Rotatory Nystagmus

This experiment investigates the hypothesis that adaptation to weightlessness influences the dynamics of the vestibulo-ocular reflex pathway through the velocity storage system. The velocity storage system is a mechanism in the central vestibular system that integrates and stores information from vestibular, visual, and proprioceptive sensors.

When a person spins around, even while spinning in total darkness, the eyes track the surrounding environment. A person attempts to track the surrounding world with the eyes. If the person spins at a constant speed in the dark, eye movements will slowly decay and cease because the vestibular apparatus requires a change in speed for stimulation. After several minutes of rotation, the subject is no longer aware of rotation. If the rotation suddenly stops, the subject immediately feels rotation in the opposite direction and exhibits a well-known phenomenon called post-rotatory nystagmus. In this experiment, the decay time for the nystagmus during and after rotation is measured early, in the middle of, and late in the mission to observe adaptation.

Optokinetic Responses

A phenomenon with characteristics similar to those observed in the Per- and Post-Rotatory Nystagmus experiment is the focus of the Optokinetic Responses experiment. When a drum with a repeating optical pattern is rotated about a subject's yaw axis, the eyes follow the drum and move in characteristic patterns. When light is extinguished, compensatory eye movements do not disappear immediately but decay over a course of time similar to that of compensatory eye velocity during rotation. This indicates that some central storage mechanism is responsible for generating the slow-phase compensatory eye movements.

When a subject rotates with eyes open in light, the surrounding room produces a full-field visual stimulus. In this experiment, nystagmus is recorded while a crew member rotates in the clockwise and counterclockwise directions in both pitch and yaw head orientations. Measurements are made first with the eyes open and in light to generate optokinetic nystagmus and then in darkness to record the ensuing optokinetic-after-nystagmus response.

Semicircular Canal Dynamics

In this experiment, the rotator is programmed to oscillate in a seemingly random fashion — changing directions and distances of rotation — so that a subject cannot anticipate motion. These movements stimulate the semicircular canals and otoliths.

Eye movements are recorded during oscillation, and the amplitude ratio (the ratio of eye movements to chair velocity) and phase relationship between the stimulus and eye movements are calculated. These measurements indicate the degree to which signals from the semicircular canals are modified by otolith receptors in weightlessness.

Visual-Vestibular Interaction

When a subject rotates around the yaw axis, horizontal nystagmus occurs; when rotation is around the pitch axis, vertical nystagmus is evident. In this experiment, the rotator/chair and optokinetic stimulus module are used separately and in concert to study the interaction between the vestibulo-ocular reflex and optokinetic nystagmus. The subject is rotated in both the yaw and pitch planes at two oscillation frequencies. During each situation, the crew member views one velocity of optokinetic stimulus module pattern movement.

The subject's visual-vestibular interaction is evaluated while the subject views the optokinetic stimulus module during sinusoidal oscillation. Control experiments measure the subject's response during rotation in darkness and as an optokinetic stimulus is presented while the rotator and subject are static.

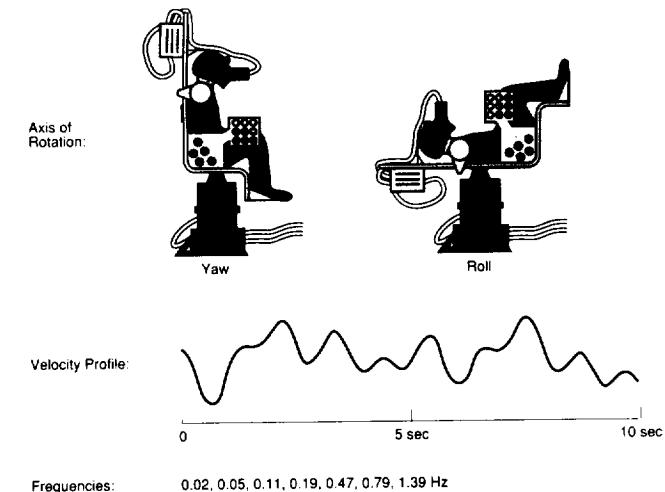
Sensory Perception

Illusions of body orientation experienced during weightlessness are important experiences to study, both from a scientific objective of understanding the integration and underlying mechanisms of the neurosensory system and from the operational need to understand and prevent, if possible, the symptoms of space motion sickness. This experiment is designed to describe, quantify, and record any changes in sensory illusions and symptoms of motion sickness that may occur during the IML-1 flight.

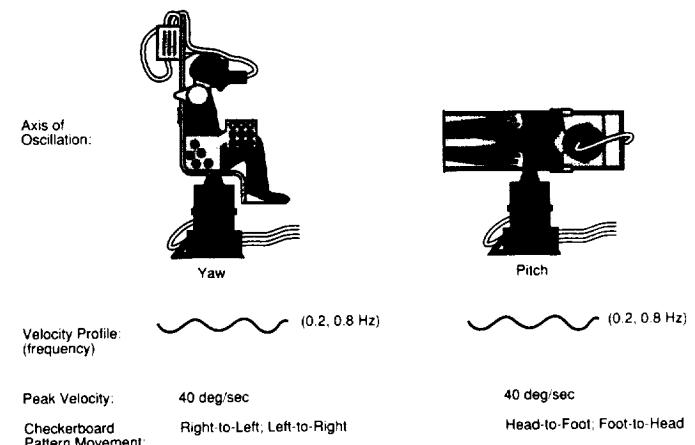
Although none of the Microgravity Vestibular Investigations are intended to induce motion sickness symptoms, the coincident occurrence of motion sickness with illusions, the nature and degree of symptoms, and records of the use of any antimotion sickness medication are very important factors to consider during data analysis. Crew members keep records of any space motion sickness symptoms during the mission, including a detailed checklist on which symptoms and motion illusions are documented. During the active experiments, the crew members record their comments on audio tapes. After the mission, scientists use the logs and tapes to analyze the conditions that brought about the symptoms.

Preflight and Postflight Testing

The above experiments are performed by the payload crew before the mission to establish a basis for comparison with flight and postflight test. A control group of non-astronauts also performs the experiments on parabolic-flight aircraft, which provide brief periods of microgravity.



Experiment conditions: Semicircular Canal Dynamics

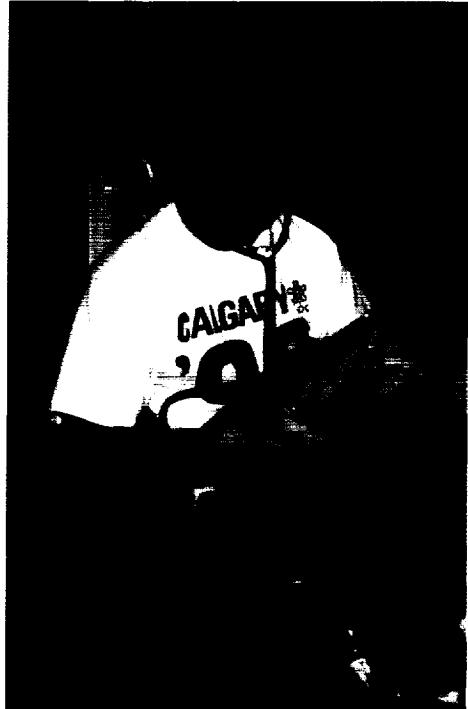


Experiment conditions: Visual-Vestibular Interaction

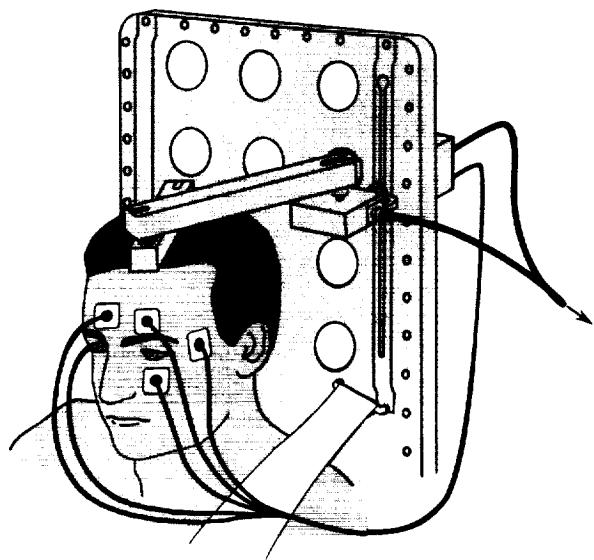


Space Physiology Experiments

■ Provided by: CSA



An investigator tests SPE equipment and experiment operations using a crew trainer that simulates the IML-1 sled.



The Rotation Experiment uses electrodes placed above, below, and to the side of a crew member's eyes to record horizontal and vertical eye movements stimulated by head motions.

Five of the six Space Physiology Experiments investigate the effects of microgravity on the human body. The most extensive focuses on the vestibular system's adaptation to microgravity. Others address blood vessel flexibility, back pain, energy expenditure, and eye movement. The sixth investigation examines how immiscible liquids separate in the absence of gravity; what is learned about this process may improve techniques used to separate biological materials on Earth.

Space Adaptation Syndrome Experiments (SASE)

Principal Investigator: Dr. Douglas G.D. Watt
McGill University
Montreal, Quebec, Canada

As many astronauts adjust to living in a weightless environment, they experience space adaptation syndrome, a condition which may include disorientation, illusions, loss of a sense of arm and leg positions, nausea, and vomiting. One theory attributes these symptoms to conflicting messages about body position and movement that the brain receives from the eyes, balance organs in the inner ears (otoliths and semicircular canals), and gravity-sensing receptors in the muscles, tendons, and joints. The body's adaptive mechanisms are complex, however, and not fully understood. The Space Adaptation Syndrome Experiments, a series of seven investigations, study the nervous system's adaptation to low-gravity.

The **Sled Experiment** measures changes in the otolith organs. On Earth, gravity acting on these organs provides a sense of up and down and helps a person stand upright by activating muscle reflexes throughout the body. In the absence of gravity, the pattern of signals that the otoliths produce is changed, and the nervous system must learn to reinterpret this information or ignore it entirely.

Wearing ear plugs and a blindfold to eliminate sound and visual cues, a test subject for the Sled Experiment is strapped into a seat on a device called the mini-sled. The seat slides gently back and forth along two rails for a maximum distance of 100 cm (40 in.) to provide a linear acceleration stimulus to the otolith organs. The test subject is further outfitted with electrodes that stimulate reflexive muscle responses in the leg. One electrode placed behind the subject's knee applies small electric shocks to the leg, and electrodes placed over the calf muscles record the responses. Acting through usual reflex pathways, the acceleration stimulus to the inner ear changes the response to the electrical shocks in the leg, and thus, it is possible to measure otolith activity in an alert human being with a functional vestibular system. To study the two independent receptors that make up each otolith organ, the subject is accelerated back and forth while seated upright and while positioned on the back.

A computer records all results during the experiment, and the data are analyzed after landing. If the nervous system learns to reinterpret the modified sensory information from the otoliths, acceleration stimuli to the inner ear should continue to influence the response recorded in the leg. If the nervous system learns to ignore that information, the variation in leg responses should gradually disappear.

The **Rotation Experiment** measures changes in the rotation-sensing parts of the inner ear (the semicircular canals). These organs provide the nervous system with information to stabilize the eyes so

that the person's gaze remains steady and the vision is clear, despite rapid and often unpredictable head movements. In weightlessness, this ability, called the vestibulo-ocular reflex, may be less effective because of interactions between semicircular canal and otolith inputs.

Strapped into the stationary mini-sled seat, the test subject wears electrodes and measuring devices that record head and eye movements. In the first test, the crew member looks at a target, closes the eyes, rotates the head to the side while trying to keep the eyes pointed at the unseen target, and then opens the eyes. The effectiveness of the vestibulo-ocular reflex is determined by how close the subject's gaze is to the target when the eyes are opened. In a complementary test, the blindfolded subject moves the head from side to side or up and down while trying to keep gazing at an imaginary fixed target. The subject's ability to keep the eyes pointed at the target is a measure of the reflex effectiveness. In a final test, the subject shifts the gaze to a series of targets projected onto a screen by a second crew member. This test studies coordination between eye and head movements, a higher level function that also relies on a functional vestibulo-ocular reflex.

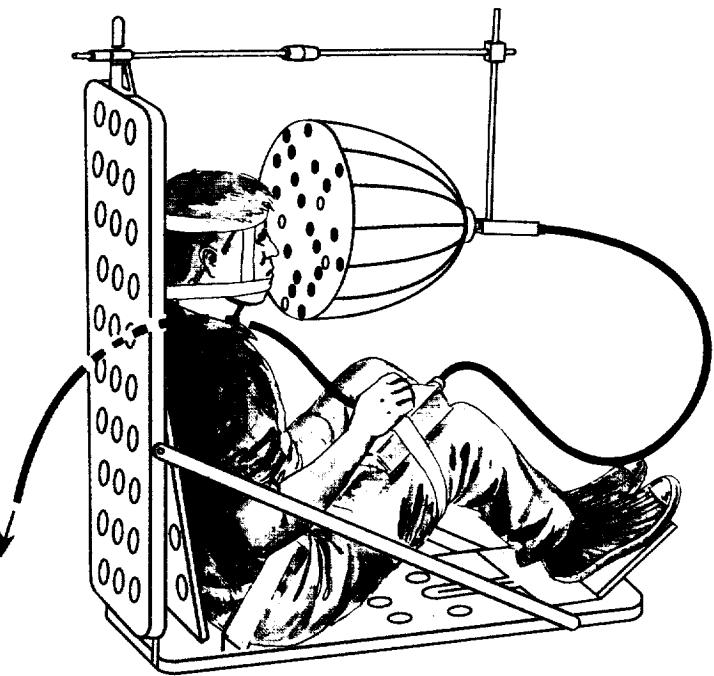
As in the Sled Experiment, all results are recorded by computer and analyzed after flight. Since gaze stability is just as important in space as on the ground, any changes in the vestibulo-ocular reflex soon after launch should be corrected within a few days.

The **Visual Stimulator Experiment** measures the relative importance of visual and vestibular information in determining body orientation. When a person looks at a rotating visual field, a false sensation of self-rotation, called circularvection, results. If the person is on Earth and seated upright, the feeling of rotation is limited by the vertical reference provided by the otolith organs in response to gravity. In weightlessness, circularvection should increase immediately and may continue to increase as the nervous system comes to rely more on visual than vestibular cues.

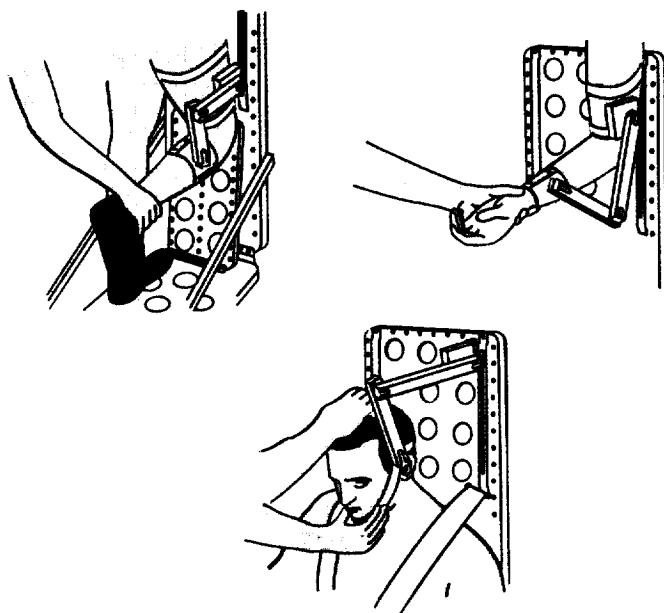
The subject, on the stationary seat of the mini-sled, stares into an umbrella-shaped dome patterned inside with colored dots. The dome turns both clockwise and counterclockwise at three different speeds: 30, 45, or 60 degrees per second. Attached to the thigh is a box with a crank that the subject turns to indicate perceived body rotation. A computer monitors both dome speed and crank speed, and the strength of circularvection is calculated by comparing these two signals. Increased circularvection strength indicates that visual orientation information is being substituted for vestibular cues.

The next three Space Adaptation Syndrome Experiments examine how the proprioceptive system is affected by microgravity. Proprioception is the sense of body and limb position and movement; it relies on receptors in muscles, tendons, and joints and on a person's knowledge of motor commands. Results of previous spaceflight experiments suggest that the sense of limb positions decreases in space, particularly in the absence of active muscle contractions. A decrease in proprioceptive ability could affect many aspects of voluntary motor control.

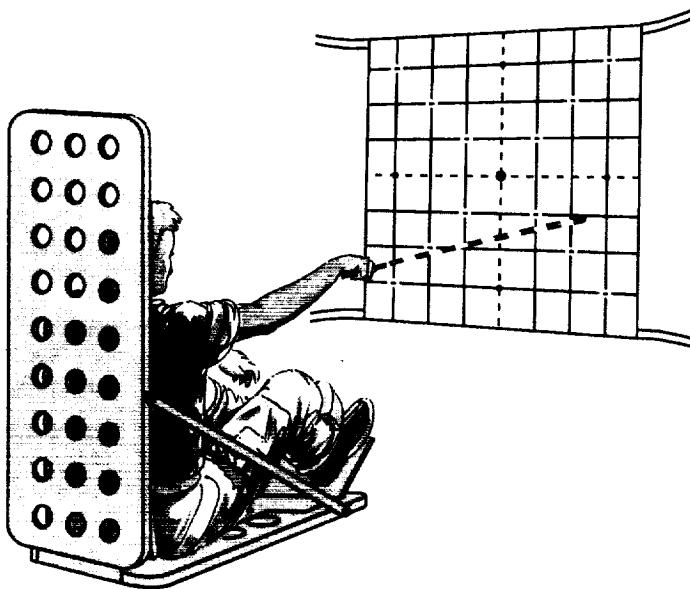
In the **Proprioception (Relaxed) Experiment**, an observer moves the head, arm, or leg of a blindfolded test subject, who remains passive during the movements. The observer bends the joint first to a reference angle and then to a slightly different angle. The subject must determine whether the second angle is larger or smaller than the reference angle and set the joint back to the original angle. A goniometer, an angle-measuring instrument, determines the actual angles, which are recorded by computer. These tests measure proprioceptive sensitivity and determine whether this sensitivity changes in weightlessness.



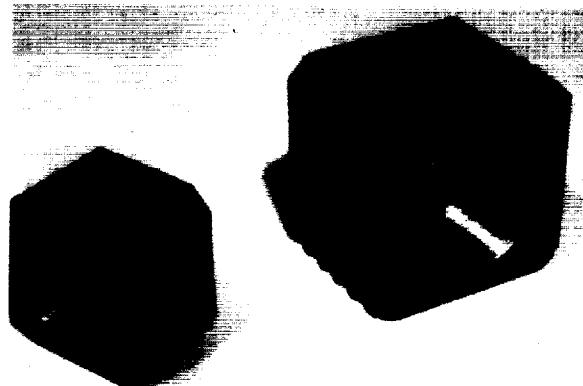
A rotating polka-dotted dome fills the crew member's field of view. This visual stimulation can cause the subject to feel like the body, rather than the dome, is rotating.



Goniometers measure the angles of knee, elbow, and head positions in the Proprioception (Relaxed) Experiment.



A grid marked with targets is used to measure pointing accuracy in the Proprioception (Active) Experiment.



Cubes with ridges spaced at different widths on each surface test fingers and toes for tactile sensitivity. The smaller cube is for the finger; the larger for the toe.

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The **Proprioception (Active) Experiment** tests how well the subject retains an accurate sense of surroundings in the absence of vision. A crew member memorizes the position of five targets on a two-dimensional reference grid, then closes the eyes, and points several times at each of the targets, using a pointer similar to a flashlight. A second crew member records how close the light beam comes to each target. The test is repeated with the subject's eyes closed only during the extension, pointing, and retraction of the arm. If the subject's pointing accuracy improves during the latter test, this may indicate that proprioceptive sensitivity improves during active muscle contractions.

The **Proprioception (Illusions) Experiment** seeks to confirm previous observations that some subjects experience an illusion of space-craft motion when performing certain maneuvers. This sensation may be the result of abnormal proprioceptive or vestibular signals in weightlessness. Test subjects make rhythmical movements, such as deep knee bends and push-ups, while observing the apparent motion of the body, the world as seen with the eyes, and the world as sensed by the proprioceptive system (eyes closed). The subjects hold to walls or railings with their hands and/or feet as necessary to maintain their position, and to provide tactile cues.

The final investigation is the **Tactile Acuity Experiment**. The human body grows taller in space (or even in bed on Earth). This happens because the spine is not being compressed by gravity forces that act from head to foot. Under such conditions, intervertebral discs expand, and the elongation can lead to partial nerve blocks, particularly ones affecting the legs. The sense of touch is also altered if a nerve block is present. In this experiment, the subject uses one finger and one toe to touch a series of surfaces on which ridges are spaced increasingly close together. The ability of the subject to distinguish the direction of the ridges allows investigators to determine tactile sensitivity. This test serves to detect possible blocks and also acts as a control for the proprioception experiments, all of which would be affected by any peripheral nerve problems.

Back Pain in Astronauts (BPA)

Principal Investigator: Dr. Peter C. Wing
University of British Columbia
Vancouver, British Columbia, Canada

Over two-thirds of all astronauts have reported back pain during spaceflight. The pain is most obvious during rest periods and may interfere with sleep. Though the pain may ease over the course of the mission, some crew members have experienced discomfort throughout a flight.

Researchers think back pain is associated with changes that take place in the length and shape of the spine in the absence of gravity. Over the course of a mission, astronauts have experienced height increases of 5 to 7 cm (2 to 2.8 in.). If back pain is associated with these height changes, it may be related to increased pressure in the discs, muscle spasms, tension on the back joints, or a stretching of the spinal cord and nerves.

The Back Pain in Astronauts experiment, which records changes in spinal shape and mobility, correlates stereo photographs of a crew member's back with the crew member's log of back pain experienced during the mission. Because the actual spine cannot be photographed, the skin on the test subject's back is marked with reference points along the shoulder blades, down the spinal column, and over the ridge of the hip bones. Using foot restraints when necessary, the crew

member assumes a series of positions: standing upright, twisting the torso to the left and right, extending the upper body backward from the hips, floating freely, standing on one foot while pulling the other foot back toward the buttocks, and raising the leg closest to the camera as high as possible with the knee straight. The test subject photographs him- or herself in each position, using a remote control device that simultaneously releases the shutters of two cameras mounted on a special bar.

After the mission, the stereo photographs are placed in an instrument that produces three-dimensional images of the back. These pairs of photographs will allow investigators to evaluate changes in height, spinal shape, and range of motion that may indicate tension on the spinal cord and nerves. By interpreting the photographs in conjunction with the subject's pain records, investigators may be able to pinpoint the cause of back pain and recommend ways to prevent or alleviate the discomfort.

Measurement of Venous Compliance (MVC)

Principal Investigator: Dr. Robert B. Thirsk

Canadian Space Agency

Ottawa, Ontario, Canada

One way the human body adapts to weightlessness is through changes in the cardiovascular system. Blood and other fluids are redistributed toward the chest and head, causing the nervous system to perceive an excess of fluids. Hormonal glands and the kidneys then act to reduce the volume of circulating fluid, and blood vessels lose tone, becoming more compliant. While these adaptations are beneficial on orbit, many astronauts experience discomfort upon return to Earth's gravity. They may feel tired, lose their peripheral vision temporarily, get dizzy, or faint — all of which are symptoms of cardiovascular deconditioning.

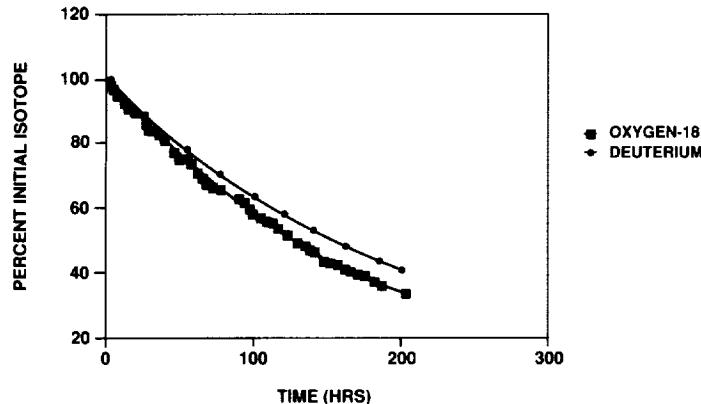
Countermeasures to these symptoms include rehydrating the body by taking salt pills with a liter of water before leaving orbit. Astronauts also don an antigravity suit containing air bladders that can be inflated to apply external pressure to the legs and lower abdomen. After return to Earth's gravity, these bladders prevent fluids from pooling in the lower body, thus maintaining sufficient blood volume in the torso and head. The procedures are helpful to some astronauts, but others still experience the symptoms of deconditioning. An improved antigravity suit may help to better counteract the effects of blood and fluid redistribution upon return to Earth after long space-flights. The findings of the Measurement of Venous Compliance study will be useful to the designers of such a suit.

Early and late in the mission, a subject's venous compliance is measured. A crew member seated on the stationary mini-sled seat wears two pairs of sensors on the right calf. These sensors are attached to an ultrasound limb plethysmograph that measures and records the volume of the leg. Ultrasonic pulses are sent from one sensor to the other through the calf, and the time required for the pulse to reach the receiver is translated by the plethysmograph into a distance that reflects the cross-sectional dimensions of the calf. The subject also wears two blood pressure cuffs, one over the sensors on the lower leg and one over the lower thigh; the test subject systematically uses the cuffs to apply various external pressures to the leg while changes in leg volume are measured. To further evaluate fluid redistribution, the girth of other body parts (arms, legs, hips, abdomen, chest, neck, and head) is measured.



SPACE
EXPERIMENTAL
EXPERIMENTS

ISOTOPE ELIMINATION



The Energy Expenditure in Spaceflight experiment records the amount of time required to eliminate isotopes of oxygen and hydrogen from the body, giving an indication of how fast the body is producing carbon dioxide.

Energy Expenditure in Spaceflight (EES)

Principal Investigator: Dr. Howard G. Parsons

The University of Calgary

Calgary, Alberta, Canada

Stress is different in space than on Earth, and the body adjusts its chemistry in response. The objectives of the Energy Expenditure in Spaceflight experiment are to determine the amount of energy (a reflection of body metabolism) spent living and working in space and to monitor changes in body composition. The findings of this study will be used to define nutritional requirements for astronauts and contribute to improved care of patients on Earth.

Carbon dioxide respiration, an indicator of energy expenditure, can be measured using a relatively new technique called the doubly labelled water method. On the first day of the mission, several crew members drink precisely known quantities of doubly labelled water, which consists of two nonradioactive isotopes — deuterium (^2H) and oxygen 18 (^{18}O). Throughout the flight, water samples from the galley water supply and urine samples are collected, and the subjects keep a daily log of what they eat and drink. On the last day of the mission, the subjects again ingest a specific amount of the labelled water. After the mission, investigators will analyze the urine and water samples (for hydrogen and oxygen isotope composition) and dietary logs, comparing them to measurements made before and after flight on the same subjects. From these data, compositional changes in the body and energy spent in orbit can be correlated.

Positional and Spontaneous Nystagmus (PSN)

Principal Investigator: Dr. Joseph A. McClure

University Hospital, University of Western Ontario

London, Ontario, Canada

One of the Space Physiology Experiments studies involuntary eye movements, or nystagmus, that occur when the otoliths and semi-circular canals in the inner ear are stimulated. Positional nystagmus is a response to gravity; as the position of the head changes relative to the direction of the pull of gravity, the direction of these eye movements changes. Spontaneous nystagmus occurs when the vestibular input from one ear differs from that of the other ear; the direction of these eye movements is not affected by the position of the head. Healthy individuals commonly experience both types of nystagmus. Spontaneous nystagmus can be an important indication of inner ear disease, however, because it increases when certain neural disorders (such as infections, vertigo, and Meniere's disease) reduce the neural input from one ear.

It is not known whether a person can experience both types of nystagmus at the same time. In Earth's gravity, it is impossible to separate positional and spontaneous nystagmus, and scientists have not been able to determine whether the eye movements are additive or whether one can displace the other. The Positional and Spontaneous Nystagmus experiment is designed to answer this question. If the two types of nystagmus can occur simultaneously, investigators want to know how the movements are combined.

It has been assumed that the nystagmus occurring when a person is in a neutral position, such as sitting or lying on the back, represents the component of spontaneous nystagmus; nystagmus evident in other positions is considered the positional component. Crew members who demonstrate positional nystagmus will be used as subjects in the experiment. Before the mission, electrodes placed at the sides of each eye and between the eyebrows will measure nystagmus as the subject's head is held in a neutral position and then as it is positioned



90 degrees to each side. The same measurements will be made in space where the gravitational effect on the inner ear, hence, positional nystagmus, should be eliminated. The nystagmus remaining in the weightless state will be compared to nystagmus observed in a neutral position on Earth to determine whether the two coincide.

Phase Partitioning Experiment (PPE)

Principal Investigator: Dr. Donald E. Brooks
University of British Columbia
Vancouver, British Columbia, Canada

One of the most effective techniques biochemists and cell biologists use to separate mixtures of biological cells and pharmaceutical materials is phase partitioning. Because the surface characteristics of each cell type differ, they can be separated by their affinities for one solution or the other in a mixture of two immiscible liquids (liquids that tend not to mix, like oil and water). In phase partitioning, cells with different surface properties are added to two immiscible polymer solutions, the mixture is shaken, and as the solutions begin to demix, the cells move according to their affinities for each of the two liquids. By adjusting the chemistry of a mixture, scientists can cause the cells of interest to collect in a particular area of the chamber: in either of the two phases or at their interface. The cell population that is then harvested should be fairly pure.

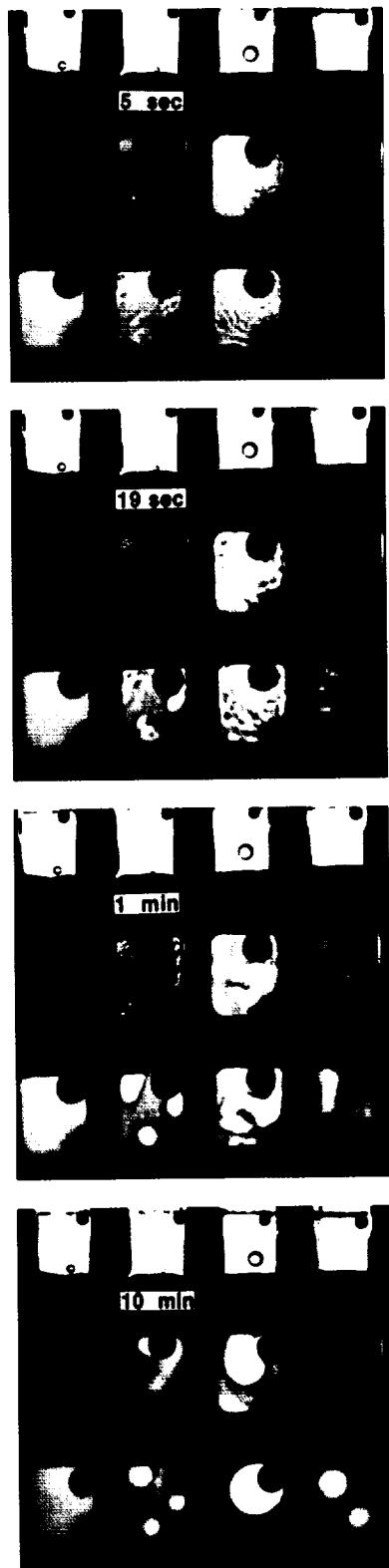
In space, where cell density and convective flows do not complicate phase partitioning, it is expected that even closely related cell types can be separated according to surface properties. The Phase Partitioning Experiment studies other factors that influence the partitioning process: the ratio of the phase volume, viscosity, salt and polymer compositions, the interface tension between the two solutions, chamber wall coatings, and chamber shape. The experiment also investigates how an electric field might be used to control demixing in a microgravity environment.

Electric fields of various strengths are applied to chambers holding six different concentrations of two immiscible polymers mixed in water. As the polymer solutions demix on orbit, the electrical fields should drive them in opposite directions, thus encouraging demixing, but it is not known how this will affect the stability of the interface between them.

The experiment hardware consists of a power control unit and a separation unit with six chambers, each of which has a top and bottom half that can be isolated from the other with the turn of a knob. The chambers also contain small mixing balls to improve the initial mixing of the polymers. The entire unit is designed to be mounted on a lightbox that illuminates the chambers so that they can be photographed.

As soon as possible after reaching orbit, a crew member reports the condition of the liquids in the chambers to give investigators an idea of how the rigors of launch have affected the solutions. The separation unit is then shaken and returned to storage. After a few days, the unit is removed from storage and photographed. The payload specialist then shakes the separation unit vigorously to start the experiments, attaches it to the power control unit, and applies the electric field. At specific intervals, photographs are made of the demixing process. Pictures are also taken when the electric field is reversed and when no electric field is applied. Before storing the experiment for reentry, the crew member again photographs the separations.

The photographs record not only the conditions within the chambers but also the electric current, polarity, and temperature readings displayed on the power control unit. These data and the analysis of the separations themselves are of interest to both life science investigators and materials science researchers who are concerned with the behavior of liquid two-phase systems, such as those involved in the production of molten metal alloys.



After 10 minutes, phase separations aboard STS 51-D are evident. The black circles in each chamber are small metal balls that help mix the phases at the start of the experiment.

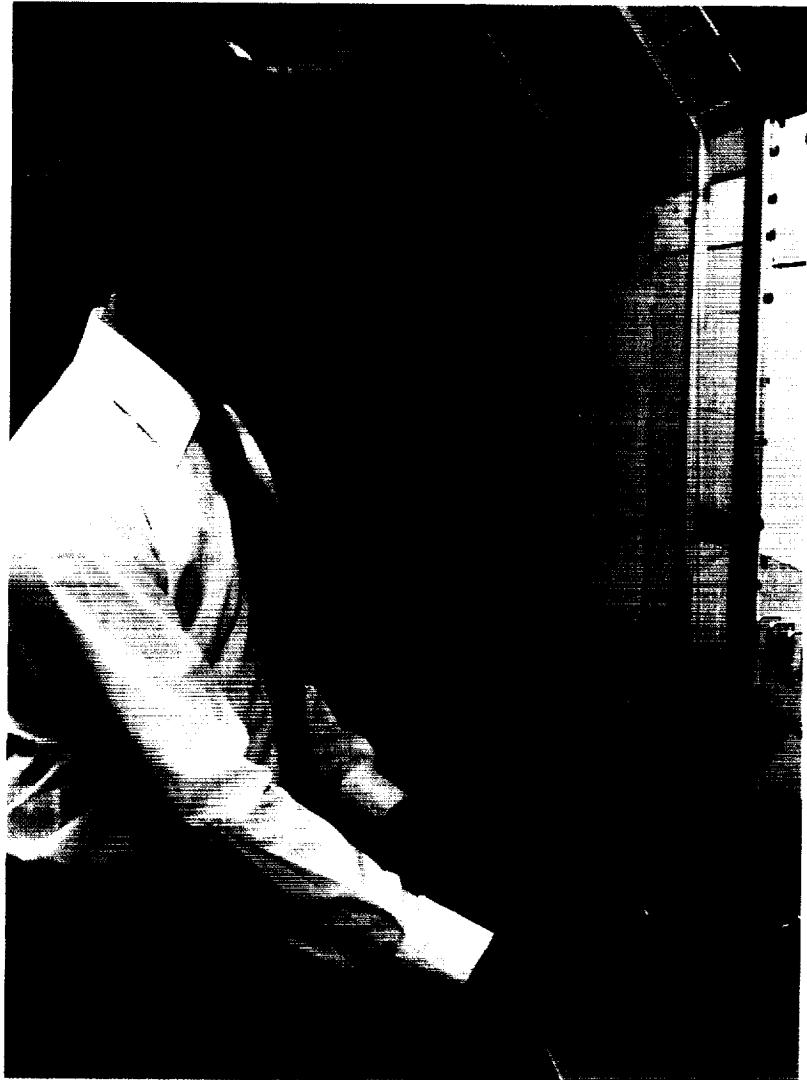
Mental **W**orkload and **P**erformance **E**xperiment

- Provided by: NASA
- Principal Investigator: Dr. Harold L. Alexander
Massachusetts Institute of Technology
Cambridge, Massachusetts, USA

Whether on Earth or in space, people tend to work more productively in settings designed for efficiency and comfort. Because well-designed accommodations enhance performance and contribute to congenial relationships among co-workers, the living and working areas of spacecraft used during months-long or years-long missions assume particular importance. The Mental Workload and Performance Experiment examines the effect of microgravity on the ability of crew members to perform tasks requiring interaction with a computer workstation.

The natural posture of the human body is different in space than on Earth; therefore, furnishings that are conducive to work in 1-g may prove uncomfortable or inefficient in microgravity. For instance, Spacelab 1 crew members had to exert considerable effort to maintain their positions at a computer workstation that had been engineered for a person standing in a typical Earth position. The IML-1 crew have a redesigned microgravity workstation with an adjustable surface for their daily planning sessions and record keeping. Cameras record the crew's range of motion and variety of positions while at the workstation. Films and videotapes, reports from the crew, and measurements of the locations of the adjustable surface will influence the design of workstations for future missions and for Space Station Freedom.

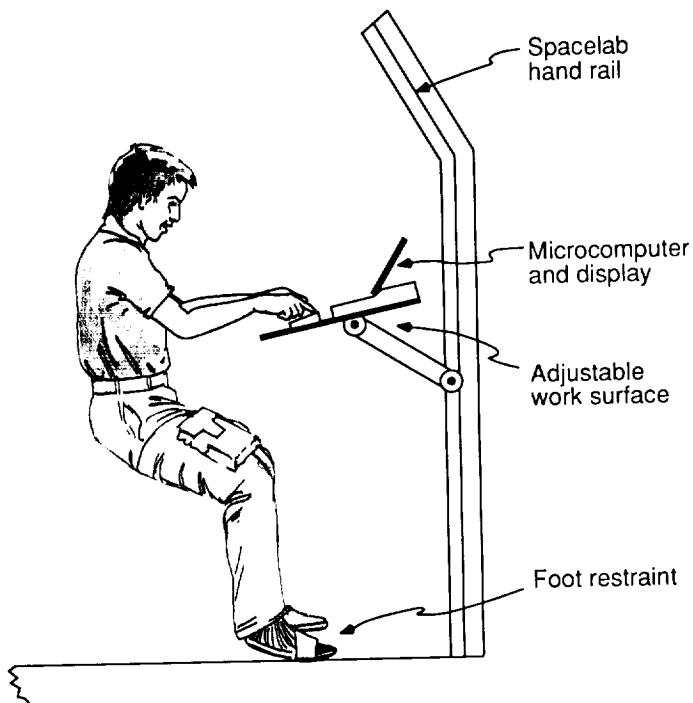
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A science team member for the Mental Workload and Performance Experiment operates a microcomputer to be used in Spacelab.

A second piece of equipment is evaluated during tests of mental function, reaction times, and physical responses. A portable microcomputer with its display monitor and keyboard are attached to a Spacelab rack handrail and positioned in the most convenient location by a crew member who then follows a program displayed on the computer monitor. After memorizing a sequence of characters, the crew member moves a cursor to corresponding targets on the screen using three different devices: keyboard cursor keys, a two-axis joystick, and a trackball. The microcomputer records the speed and accuracy of the movements and the time needed to interpret the instructions. These data are complemented by the crew's evaluations of the equipment. Because different fine motor skills are involved in manipulating the devices, the results of the exercise will shed light on the most efficient design for performing specific computer tasks in space.

The payload crew performs these activities several times before, during, and after the flight to determine whether mental and physical performance are influenced by adaptation to microgravity or by subsequent readaptation to Earth's gravity. Results from preflight, flight, and postflight exercises conducted by the payload crew and a ground control group will be compared.

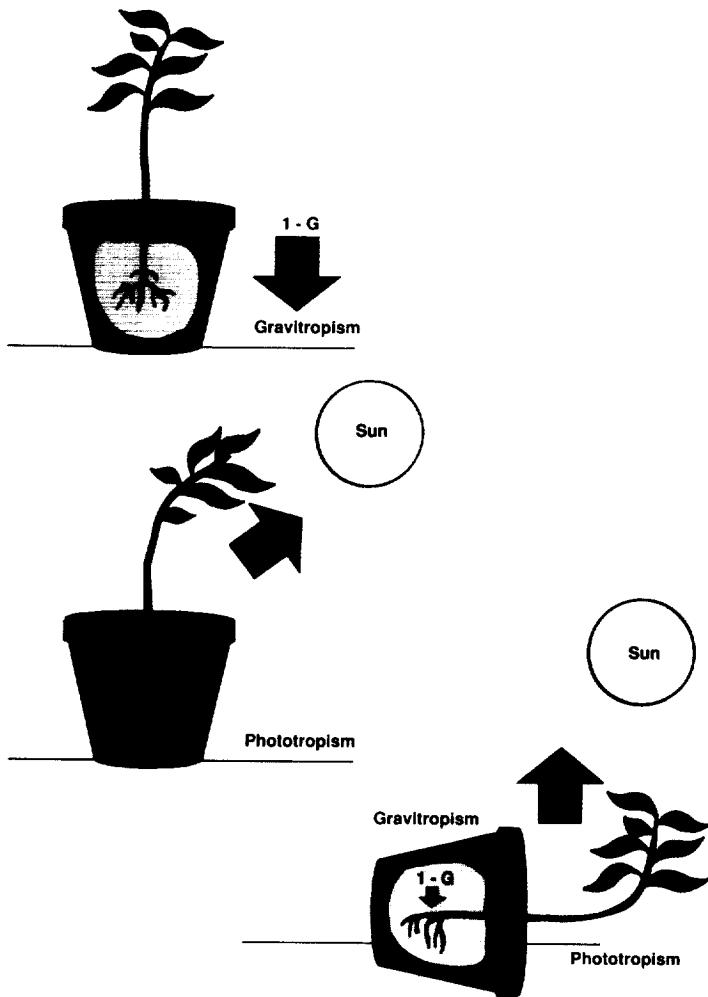


During IML-1, payload crew members evaluate the effectiveness of a joystick, keyboard, and track ball to move the computer's cursor.



G P P F ravitational lant hysiology acility

■ Provided by: NASA



Several types of plant behavior are studied in the Gravitational Plant Physiology Facility. Gravitropism is the way plants grow in response to the pull of gravity. When placed near a window, plants exhibit phototropism (bending toward the light source). This behavior can be easily observed by placing a plant on its side; within minutes the roots and stem begin to reorient themselves in response to gravity and light.

Scientists know that plants respond to gravity and light. They have observed that the roots of a plant placed on its side reorient themselves within minutes and begin to grow downward again. Similarly, they know that a plant placed near a sunny window quickly begins to bend toward the light. But scientists want to know more about the mechanisms that control these responses. How do plants know the difference between up and down? How do the response patterns for gravity differ from those for light? How are these responses related?

On Earth, it is difficult to examine a plant's response to gravity (gravitropism) and light (phototropism) because Earth's constant gravitational pull complicates experiment results, making precise analyses of plant behavior impossible. In space, this research can be done without complications from a constant 1-g force.

On the IML-1 mission, the Gravitational Plant Physiology Facility, located in a Spacelab double rack, provides the tools necessary to study gravitropism and phototropism. Like a small botanical laboratory, the facility's components include centrifuges, lights, videotape recorders, and plant-holding compartments. The two experiments conducted in this facility share much of this equipment.

Gravity Threshold (GTHRES)

Principal Investigator: Dr. Allan H. Brown
University of Pennsylvania
Philadelphia, Pennsylvania, USA

Gravity Threshold investigates the changes that occur when plants are exposed to different levels and durations of gravity. The experiment uses a centrifuge to determine the sensitivity and threshold of the gravity-detecting mechanism of oat plants (*Avena sativa*). Oat seedlings are used because they develop quickly and have been used in more studies of gravitropism than any other plant, providing scientists with a data base for designing new experiments. Gravity Threshold also studies how a growing plant responds to altered gravitational fields and how microgravity affects a plant's structure. Until now, investigations of this kind were made only on Earth where their results were distorted by gravity.

Plant samples used early in the Gravity Threshold experiment germinate on the ground. For specimens used later in the mission, a crew member plants the seeds in the Gravitational Plant Physiology Facility in soil supplied with the right amount of water, and germination occurs in space. A series of oat seeds is planted so that seedlings of the appropriate age and height are available when the experiment begins. Once in flight, the plants are transferred to a 1-g centrifuge, called a culture rotor, where they continue to develop normally under a 1-g force until they are ready to be used in the experiment.

All the seedlings are cultured in containers, called cubes, with windows that can be penetrated by infrared radiation but not by visible light. This prevents exposure of the plants to light, which induces phototropic responses and could cloud the interpretation of the gravitropic responses that the experiment measures. The seedlings can grow on their stored food for several days in complete darkness. As the seedlings grow, infrared radiation from a bank of emitting diodes is directed through the cube windows. The contents of the cube including the plants reflect this light, and the resultant infrared image is recorded by a camera.

When the plants are ready, the cubes are placed in another centrifuge, called a test rotor, to expose them to various combinations of acceleration durations (2 minutes to 2 hours) and intensities. This

method allows scientists to study different degrees of gravitational pull (0.2-g to 1.0-g) without interference from the constant 1-g force present on Earth. During the experiment, plant images are recorded by time-lapse video. Gas samples of carbon dioxide and ethylene, which are important factors in the development of the seedlings, are taken from the plant cubes; other variables, such as experiment temperature, centrifuge speed, and time of events, also are recorded. The video, plant samples, and other data are stored for postflight analyses.

Response to Light Stimulation: Phototropic Transients (FOTRAN)

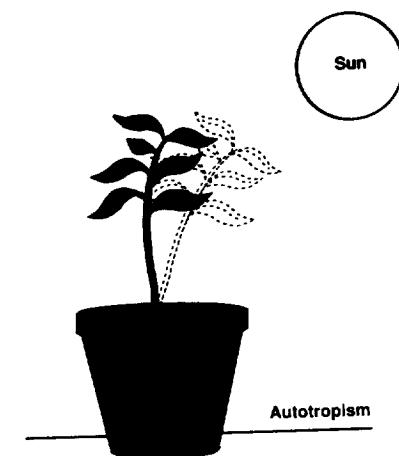
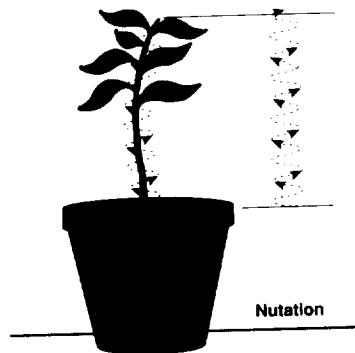
Principal Investigator: Dr. David G. Heathcote

University of Pennsylvania

Philadelphia, Pennsylvania, USA

This experiment investigates how plants respond to light in microgravity and examines the impact of microgravity on two other interesting types of plant behavior. The first, nutation, is the helical growth pattern of plant stems. The second, autotropism, is the straightening often observed in plants that were curved during gravitropic or nutational movements. Growth patterns, such as phototropism, nutation, and autotropism, occur naturally on Earth, and scientists want to learn details of how the movements change in microgravity.

The Response to Light Stimulation experiment uses wheat seedlings (*Triticum aestivum* cv *Broom*) planted both before the mission and in space. During flight, the seedlings are grown in a culture rotor at 1-g. When they have reached the appropriate size for the experiment, the seedlings are transferred to a 0-g chamber where they are exposed to a pulse of blue light, which ground studies have shown to be an effective way to evoke a phototropic response. Different groups of seedlings receive different durations of light exposure. The seedlings' responses are monitored by an infrared-sensitive, time-lapse video camera and recorded for analysis. Some samples are preserved chemically to fix their growth in microgravity for study after the flight. Carbon dioxide and ethylene gas samples are taken from the plant cubes for postflight analysis of the environmental conditions during the plant growth.



Plant stems grow upward in a helical pattern, called nutation. Autotropism is the straightening often observed in plants that have been curved in a phototropic or nutational movement.

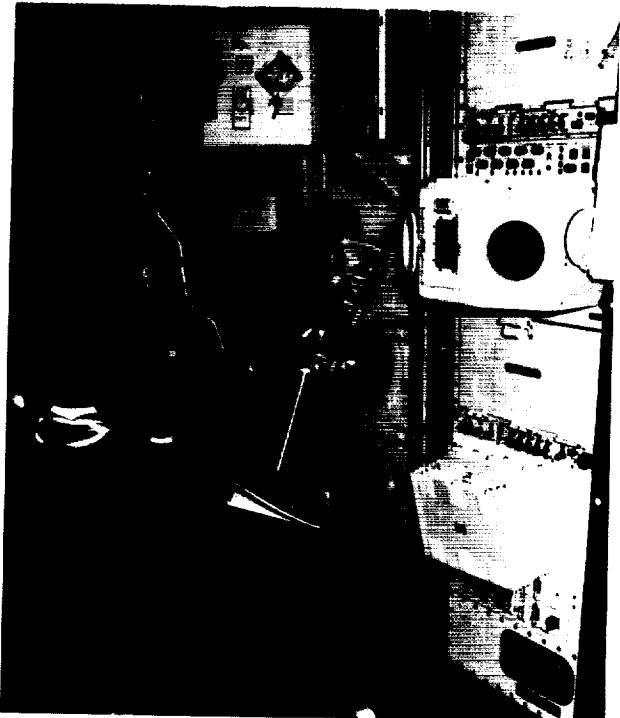
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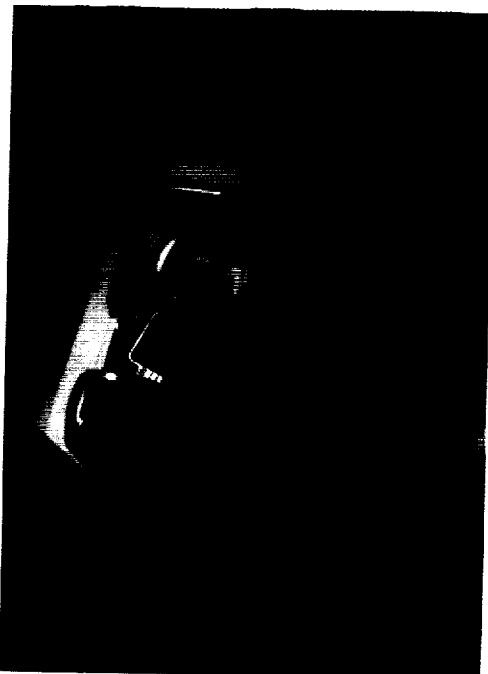
Dr. David Heathcote, principal investigator for FOTRAN, plants wheat seeds in cubes supplied with the right amount of soil and water.

Biorack

■ Provided by: ESA



A Spacelab D1 crew member prepares to load samples into a Biorack incubator. This facility, located in the rack to the right of the crew member, will be used to continue studies of microorganisms, cells, and small plants on IML-1.



Crew members handle specimens in the contained environment of the Biorack glovebox.

Biorack is a large multipurpose facility designed for studying the effects of microgravity and cosmic radiation on numerous small life forms: cells, tissues, small organisms, and plants. This facility accommodates hundreds of specimens per flight for investigations designed by life scientists around the world.

Spacelab missions are ideally suited for these studies because the specimens are small enough to be observed and manipulated in relatively large numbers, and they evolve through several stages of their lives, sometimes even several generations, over the course of a Spacelab mission. Scientists can preserve specimens at various stages of development and return them to Earth for detailed analyses that reveal not only how organisms respond to microgravity or radiation but also how gravity affects them.

Previous Biorack experiments on Spacelab D1 in 1985 provided striking evidence that microgravity affects a variety of organisms — from bacteria to fruit flies. For IML-1, eight Spacelab D1 experiments with frog eggs, fruit flies, lentil roots, slime molds, spores, stick insects, bacteria, and radiation monitors are repeated with hardware and experiment procedures that were modified based on results from the earlier flight. Nine new experiments are carried out with human cells, mouse cells, nematode worms, yeast, and plants.

There is still much that we do not understand about how gravity influences life. No general rules apply to all cells or organisms. Biorack investigations ask many questions: What role does gravity play in helping plants orient their roots down in soil? Can eggs be fertilized in space? Does microgravity affect embryo development and later generations of offspring? Are bacteria more resistant to antibiotics in space? Do organisms have an internal clock that dictates certain biological functions in space and on the ground? Does microgravity affect cell functions? Does low-gravity speed up reproduction and other processes in cells and small organisms? Which genes are most sensitive to the high-energy radiation of space?

The Biorack facility is located in a single Spacelab rack with one incubator mounted in another rack. Biological samples are stored in the middeck during launch and in the middeck and the Life Sciences Laboratory Equipment (LSLE) refrigerator/freezer during landing. The hardware for each investigation is unique, but all the Biorack experiments fit in either Type I containers (about the size of cigarette packs) or Type II containers (about the size of pint ice cream cartons). Experiment samples and hardware are carried in 149 Type I containers and 11 Type II containers.

Soon after the crew enter Spacelab, they turn on Biorack and check out the incubators, cooler, and freezer. Then, they transfer the experiment containers from the middeck to one of Biorack's three incubators, which operate at different temperatures needed to support various investigations. Each incubator has static racks that keep containers in a microgravity environment and two centrifuges that expose samples

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to 1-g. The centrifuges are very important experiment controls because they help biologists discriminate between the influence of microgravity and other space conditions, such as radiation, by duplicating the same experiments in a simulated 1-g environment.

Operations for individual investigations are performed at predetermined times during the mission. Approximately 2 hours after each experiment begins in space, scientists at the Kennedy Space Center start identical ground control experiments. On the ground and in space, samples are preserved at regular intervals so that biologists can trace microgravity effects to specific developmental phases. Some samples are fixed with a preservative and placed in the Biorack cooler or freezer (which are both part of the same unit) for return to Earth; other samples are frozen inside another Spacelab freezer.

When crew members open the experiment containers for observations, video recordings, and microscopy, they use the Biorack glovebox, an enclosed environment that protects samples from contamination and prevents liquids from escaping. Crew members handle the specimens with their hands inside gloves that extend into the sealed work area. A microscope mounted on the glovebox door can be used to observe organisms such as the slime mold. A video camera also fits on the glovebox door.

Just before the crew leave Spacelab, they transfer samples to special middeck containers and turn off Biorack. About 3 hours after landing, samples are returned to the Biorack team who take them to the Kennedy Space Center for preliminary analyses by the principal investigators.



Friend Leukemia Virus Transformed Cells Exposed to Microgravity in the Presence of DMSO (FRIEND)

**Principal Investigator: Dr. Augusto Cogoli
ETH Institute of Biotechnology
Zurich, Switzerland**

Before people can live in space for extended periods, we must understand how human cells reproduce and function in space. Previous experiments have shown that blood cells — both white blood cells that fight infection and red blood cells that transport oxygen throughout the body — are sensitive to gravity. By learning how gravity affects these cells, we can understand its role in certain cellular processes on Earth and in space.

On Earth, cells that would normally differentiate to become blood cells are sometimes transformed by the leukemia virus and become cancerous Friend Leukemia cells.

Such cells do not produce hemoglobin, the red protein that carries oxygen from the lungs to the body tissues and carbon dioxide from tissues to the lungs. Ground-based experiments have shown that Friend cells exposed to a drug called dimethylsulfoxide (DMSO) produce hemoglobin, making the cells red. Scientists do not know whether this happens because the drug activates a gene regulating hemoglobin synthesis or because it inhibits mechanisms repressing the gene. By studying these cells in microgravity, scientists may be able to determine how the gene is regulated. Since experiments indicate that other blood cells are not produced as rapidly in space, scientists want to see if the Friend cells differentiate and produce hemoglobin at a different rate in space than they do on the ground.

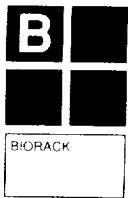
Postflight analysis will include biochemical and microscopic studies. The hemoglobin content of each culture will be measured and compared with ground control cultures.

Proliferation and Performance of Hybridoma Cells in Microgravity (HYBRID)

**Principal Investigator: Dr. Augusto Cogoli
ETH Institute of Biotechnology
Zurich, Switzerland**

This investigation centers on how cells synthesize and secrete natural products in microgravity. If cells produce material more rapidly in space, it may be practical to manufacture some pharmaceutical products in space. When white blood cells (B-lymphocytes) fuse with cancerous tumor cells (melanoma cells), they form hybridoma cells. Like cancer cells, these hybridomas reproduce rapidly, but they secrete monoclonal antibodies that fight disease as do white blood cells. Thus, hybridoma cells produce valuable antibodies more rapidly than white blood cells alone.

Two types of cells — HeLa cells (cells from cancerous cervical tissue) and K462 cells (cancer cells similar to Friend Leukemia cells) — are fused with B-lymphocytes to form hybridomas that are grown in space. After the mission, scientists can compare the amount of certain antibody secretions by space-grown cells to those grown on Earth.



■ **Dynamic Cell Culture System (CULTURE)**

Principal Investigator: Dr. Augusto Cogoli
ETH Institute of Biotechnolog
Zurich, Switzerland

A bioreactor for growing cell cultures continuously in space is tested during IML-1. Two Dynamic Cell Culture Systems fit in each of four Type I containers. Each system has a 0.2-ml (0.006-oz) culture chamber with a window. The cell chamber contains Syrian hamster kidney cells. Previous experiments suggest that these kidney cells may reproduce faster in microgravity and secrete greater amounts of urokinase (an enzyme used in drugs that dissolve blood clots) during shorter periods.

An osmotic pump automatically supplies fresh nutrients needed for cell production. Osmosis is a process that occurs in animals and plants, moving substances such as fluids and gases from one place to another through a membrane. For example, molecules pass from one side of a semi-permeable membrane, like a cell cytoplasmic membrane, to the other side naturally because of pressure differences on each side of the membrane. The osmotic pump, a rubber container, is gradually squeezed empty of cultural medium by osmotic pressure. As culture nutrients flow into the cell container, old medium is forced out. The system is designed to operate automatically for 2 weeks.

■ **Chondrogenesis in Micromass Cultures of Mouse Limb Mesenchyme Exposed to Microgravity (CELLS)**

Principal Investigator: Dr. P.J. Duke
Dental Science Institute
University of Texas
Houston, Texas, USA

This investigation studies how embryonic limb bone cells (chondrocytes) produce cartilage in cell cultures exposed to microgravity. Cartilage impairments found in rodents flown on previous space flights are similar to those observed in skeletal malformations in children. By studying how gravity affects cartilage differentiation, we may learn subtle aspects of cartilage development on Earth. The experiment may also help clarify how bones heal in space. If an astronaut breaks a

bone during a 3-year Mars mission, will it heal properly? Cell division to produce cartilage and new bone would be part of the repair process.

Before bone formation, the whole skeleton is laid out in cartilage. If something happens during this process, bone development may not be normal. This experiment uses cells from mouse embryo legs at a stage when there is no bone, only cartilage. The cells are grown in a nutrient medium that is frozen for biochemical analysis postflight. Total cartilage formation in each culture is determined by measuring the area of the culture that turns dark blue with a stain specific for cartilage. To spot differences in collagen development, scientists measure the length, width, and size of stained cartilage fibers. Very precise analysis with cameras, microscopes, and digital computers helps determine collagen fibers, cartilage areas, and structures inside cells.

■ **Effects of Microgravity and Mechanical Stimulation on the in-vitro Mineralization and Resorption of Fetal Mouse Bones (BONES)**

Principal Investigator:
Dr. Jacobos-Paul Veldhuijzen
ACTA Free University
Amsterdam, The Netherlands

Life scientists are concerned about the bone demineralization that astronauts experience in weightlessness. If calcium loss continues indefinitely during space flight, the likelihood that crew members will break these weakened bones increases the longer a mission lasts. Significant calcium loss also affects a person's ability to function in Earth's gravity after a mission. Before long spaceflights can be planned, the effects of microgravity on bone growth, maintenance, and repair must be understood.

Ground-based studies have shown that, under pressurized conditions, embryonic mouse leg cartilage calcifies into bone more quickly than under normal atmospheric pressure and that developing bones release calcium (resorption) into their growth medium more slowly. Human bones being stressed in gravity act the same way. This suggests that uncompressed mouse bone cultures respond in a fashion similar to human bones in microgravity. If so, the mouse tissue



can serve as a model for ground-based studies into the effects of microgravity on mineralization and resorption of skeletal tissues.

In this experiment, investigators study the response of embryonic mouse leg bones to microgravity. Scientists postulate that the uncompressed cultures grown outside the centrifuge (under microgravity conditions) should respond like bones that are unstressed in a weightless environment. To test this hypothesis, both the microscopic structure and the biochemical make-up of the cultures are analyzed to determine their mineralization and resorption rates.

■ Why Microgravity Might Interfere with Amphibian Egg Fertilization and the Role of Gravity in Determination of the Dorsal/Ventral Axis in Developing Amphibian Embryos (EGGS)

Principal Investigator: Dr. Geertje A. Ubbels
Hubrecht Laboratory
Utrecht, The Netherlands

Scientists are not sure what role gravity plays in the earliest stages of embryonic development that determine the future dorsal (back) and ventral (front) sides of the body. They may be able to clarify gravity's role by studying fertilization and embryo formation of frogs in space.

Before fertilization, each frog egg is positioned inside a sticky membrane, which holds the parts of the egg random with respect to gravity. When a sperm fertilizes the egg, the egg is freed from the outer membrane (cleaved). Due to mass differences in the yolk, gravity aligns the part of the egg's surface with the least yolk up and the part of egg's surface with the most yolk down. In normal cases, the sperm's point of entrance will become the front side of the embryo. However, if gravity disturbs the yolk distribution inside the fertilized egg, this may not happen. In space, the sperm entrance point should always become the ventral side.

Investigators want to confirm that this is true and also that eggs can be fertilized in space. Frog eggs will be fertilized in space, incubated, and then preserved during various phases of embryonic development. Postflight, samples can be compared to see if fertilization and development proceeded normally.

■ Effect of the Space Environment on the Development of *Drosophila Melanogaster* (FLY)

Principal Investigator: Dr. R. Marco
Department of Biochemistry
Institute of Biochemical Investigations
University of Madrid, Madrid, Spain

This experiment studies the differentiation (embryogenesis) of fruit fly eggs exposed to microgravity. These eggs have well-established internal structures that are assumed to be essential for normal embryo development after egg fertilization. Does gravity play a role in organizing the egg's yolk? Does this affect embryo development?

IML-1 scientists will examine embryos exposed to microgravity for varied periods to determine which stages of development are sensitive to gravity. When they are returned to Earth, the larvae and embryos will be fixed and prepared for microscopic analysis. The live flies will be placed in individual tubes, and their behavior is monitored every day until their death.

Results from an identical experiment flown on Spacelab D1 indicate that fruit fly embryos develop in microgravity, but their development is altered. The effects observed on Spacelab D1 were more pronounced in larvae hatched after 2 days in weightlessness, when most of the differentiation process had occurred. Since the IML-1 mission is longer, it will be possible for some embryos to develop entirely under microgravity conditions. Investigators will examine them to see whether abnormalities are more pronounced or whether hatching and development processes adjust and return to normal.

Spacelab D1 results also showed that the average life span of male flies was reduced, with females apparently being unaffected. This may be related to the speeding up of biological processes observed in other organisms. For IML-1, separate populations of male flies are flown so that their life spans can be measured.



Genetic and Molecular Dosimetry of HZE Radiation (RADIAT)

Principal Investigator:
Dr. Gregory A. Nelson
NASA Jet Propulsion Laboratory
Pasadena, California, USA

One of the major features of the space environment is the presence of cosmic rays or HZE (high energy and charge) particles. Although they account for only about 1 percent of the particles of radiation in space, they contribute about half of the total absorbed radiation dose. We must understand the biological effects of exposure to cosmic rays to protect space travelers on long missions.

On the IML-1 mission, the microscopic soil nematode (roundworm), *Caenorhabditis elegans*, is used in experiments to "capture" mutations caused by cosmic rays, to evaluate whether the genetic processes of chromosome segregation and recombination occur normally in space, and to test whether development and reproduction proceed normally in microgravity for up to three generations. The nematode is one of the best understood animals available to biologists. It grows quickly on inexpensive food sources with a generation time of about 3 days, and each individual produces 280 offspring through self-fertilization. The ancestry of every one of the adult nematode's 1,031 cells is known from the moment of fertilization; the "wiring" pattern of its nervous system has been described at electron microscope resolution.

The worms are placed in containers with detectors that record the number of HZE particles and the total radiation dose. Containers are placed at various locations in Spacelab to sample the radiation environment under different levels of shielding. After the mission, the plastic detectors are chemically processed to record cosmic ray tracks, which show where particles penetrated the worms. The worms are examined for genetic mutations and development progress.

Dosimetric Mapping Inside Biorack (DOSIMTR)

Principal Investigator: Dr. G. Reitz
Institute for Flight Medicine, DLR
Cologne, Federal Republic of Germany

The IML-1 experiments are done in an environment with electromagnetic radiation, charged particles, and secondary radiation. This flux is not constant but changes with spacecraft inclination and altitude, solar activity, and Earth's magnetic field. Moreover, the shielding of the spacecraft is only approximately known and depends on the payload and its arrangement.

This experiment documents the radiation environment inside Biorack and compares it to theoretical predictions. Other experiments inside Biorack need this information to determine whether changes to samples are caused by radiation or microgravity. Dosimetric stacks, each with 20 to 100 sheets of plastic detector foils (cellulose nitrate, Lexan, and CR 39) and nuclear emulsions of different radiation sensitivity are packed inside aluminum containers with 1-mm (0.04 in.) walls. They are placed in different parts of Biorack. After the mission, particle hits recorded by the dosimeters are measured to reveal absorbed doses from medium-energy neutrons up to about 1 million electron volts. The plastic detectors are developed like photographic emulsions, and particle tracks can then be seen under a microscope.

During the Spacelab D1 mission, similar detectors recorded varying doses in different parts of Biorack, indicating that heavy ion fluxes vary even in a single Spacelab rack. These results clearly show that to protect experiment integrity, it is necessary to measure radiation fields as close as possible to biological specimens.



■ Embryogenesis and Organogenesis of *Carausius Morosus* under Spaceflight Conditions (MOROSUS)

Principal Investigator: Dr. H. Buecker
Institute for Flight Medicine, DLR
Cologne, Federal Republic of Germany

Before humans can live for extended periods of time in space, the effects of microgravity and long-term exposure to heavy ions of radiation from the Sun and other celestial objects must be known. Results from a Spacelab D1 experiment suggest that growth is inhibited in eggs of *Carausius morosus*, a stick insect. The larvae from all eggs penetrated by heavy ions under microgravity had shorter life spans and an unusually high rate of deformities.

For the IML-1 experiment, stick insect eggs at earlier stages of development are sandwiched between layers of radiation detectors. This layered arrangement of eggs and detectors allows scientists to trace the paths of cosmic radiation passing through the layers and identify the eggs that are hit. All eggs develop under the influence of microgravity.

After the mission, scientists will determine how many eggs hatched; the rate of growth; how strong the insects are that survive the mission; how many insects develop abnormalities; how many females hatch in comparison to the number of males; and how many, if any, genetic changes occur in the individuals that matured during the mission.

■ Gravity Related Behavior of the Acellular Slime Mold *Physarum Polycephalum* (SLIME)

Principal Investigator: Dr. Ingrid Block
Institute for Flight Medicine, DLR
Cologne, Federal Republic of Germany

Many living things, including people, perform activities, such as sleeping, at regular periods. Are these activities controlled by an internal biological clock or triggered by external cues, such as day and night cycles, Earth's rotation, and gravity? In space, these cues are absent, and investigators can examine organisms to see if functions occur in regular circadian time frames.

Physarum polycephalum, a slime mold that lives on decaying trees and in soil, has regular contractions and dilations that slowly move the cell at about 1 cm (0.39 in.) per hour. Protoplasmic streaming, which is easily

visible, is maintained by these periodic contractions and relaxations of the organism's veins, internal cell canals that carry protoplasm. On Earth, gravity modifies the direction of cell movement and the force of streaming. Any direct effects of microgravity should alter this movement and be evident as a change in circadian rhythm.

After the mission, IML-1 data will be compared with Spacelab D1 results. These results revealed that the frequency of the contractions was slightly shortened at first but returned to normal as the slime mold adapted. This indicates that the organism's internal clock operates unopposed by gravity. The streaming movements were faster and stronger. The movements may have been faster because it takes less energy to move in microgravity than it does in 1-g; this alteration in behavior shows that even cells with no special gravity receptors are influenced by gravity.

■ Microgravitational Effects on Chromosome Behavior (YEAST)

Principal Investigator: Dr. Carlo V. Bruschi
United Nations International
Development Organization
Trieste, Italy

Scientists have measured the effects of microgravity and radiation on chromosomes. Microgravity alters spindle formation and thereby alters chromosome structure and segregation during mitosis (identical cell division to produce new cells). Radiation can act at the molecular level producing changes in DNA structure, which are passed on by cells undergoing meiosis (cell division to reduce chromosomes in reproductive cells).

For this experiment, microgravity and radiation effects are monitored separately in the same organism by measuring genetic damage during mitosis and meiosis. The common yeast (*Saccharomyces cerevisiae*) is used because it is capable of undergoing both meiosis and mitosis. Therefore, scientists can monitor frequencies of chromosomal loss and structural deformities and DNA mutation rates with a resolution impossible in higher organisms. Postflight genetic studies of mitotic and meiotic cells incubated in space will reveal chromosome abnormalities, preference for sexual versus asexual reproduction, numbers and characteristics of male and female cells, anomalies in mitosis and meiosis, viability of spores, and changes in sporulation.



Growth and Sporulation in *Bacillus Subtilis* under Microgravity (SPORES)

Principal Investigator:
Dr. Horst-Dieter Menningmann
Institute for Microbiology
University of Frankfurt
Frankfurt, Federal Republic of Germany

Bacillus subtilis bacteria proliferate rapidly, making them excellent subjects for studying cell division. When cell division halts because the culture nutrients are exhausted, cell differentiation begins, leading to the formation of spores. To better understand cell differentiation — the way that cells with different functions are produced — scientists will study the onset and growth of bacteria spores in microgravity.

It is believed that the distribution of a particular enzyme causes sporulation to occur. The influence of microgravity on this distribution and the way the enzyme acts in the absence of gravity are studied by examining the structure and biochemistry of the spores after the mission. Biologists also will examine the internal structure and shape of the cells, the rate of growth and differentiation, and the arrangement of large molecules in the cells.

On the Spacelab D1 mission, this experiment confirmed that microgravity causes bacteria to reproduce more rapidly; this is of concern because experiments also indicate that antibiotics are less effective in killing bacteria in space. The experiment revealed a striking reduction in the rate of sporulation and thus in cell differentiation. However, since the 1-g control failed, these results need to be confirmed on IML-1.

Studies on Penetration of Antibiotics in Bacterial Cells in Space Conditions (ANTIBIO)

Principal Investigator: Dr. René Tixador
National Institute of Health and Medical Research
Toulouse, France

In space, bacteria may be more resistant to antibiotics because the structure of their cell walls may be thicker in microgravity. This wall is a barrier between the drug and target molecules in the cell, and a thicker wall could be more effective in preventing antibiotics from destroying bacteria. The increased proliferation of bacteria in space could also make antibiotics less effective.

This investigation studies the effect of different antibiotics on the proliferation of *Escherichia coli* bacteria. An antibiotic (dihydrostreptomycin) is marked with a radioactive tracer (tritium ^3H) so that investigators can follow its path through the cells. Space-grown bacteria samples are exposed to various concentrations of the antibiotic.

Immediately after landing, investigators test cultures to determine the minimal quantity of the antibiotic that stopped bacteria growth. Then the samples are transported to the Kennedy Space Center where scientists measure the number of living cells in each culture. They compare the proliferation rates of bacteria exposed to antibiotics to those that were not exposed; both sets of bacteria grown in space are compared to sets grown on the ground. The cells are examined under a microscope to determine how much antibiotic penetrated each bacterium's cell wall.

Transmission of the Gravity Stimulus in Statocyte of the Lentil Root (ROOTS)

Principal Investigator: Dr. Gérald Perbal
Laboratory of Cytology
Pierre and Marie Curie University
Paris, France

On Earth, the roots of most plants can clearly perceive gravity since they grow downwards. How they do this is still a mystery. For this experiment, biologists study the growth of *Lens culinaris*, lentil seedling roots, and try to understand how these plants sense gravity. Lentil roots have statocytes that contain dense particle structures (statoliths) that move freely in the direction of gravity. In microgravity, statoliths are distributed randomly in growing root tips. After microgravity exposure, the root samples are put on a 1-g centrifuge to see if their statoliths still sense gravity. Their responses are photographed and the roots are preserved.

This experiment was flown on Spacelab D1, and the roots lost the ability to orient themselves in microgravity, but the loss was not permanent. When the seeds were put on the 1-g centrifuge, they reoriented themselves in the direction of the simulated gravity vector. For IML-1, some seedlings are monitored by a new automatic photography system for extended periods. This way investigators can determine the minimum amount of simulated 1-g exposure required for the plants to regain gravity sensitivity and reorient roots.



Spacelab D1 analysis of the cellular structure of the roots revealed that a theory about how plants detect gravity is probably incorrect. According to the theory, statolith contact with an elaborate membrane (the endoplasmic reticulum) is essential for the cell to detect gravity. Although the Spacelab D1 plant statoliths were located in the lower half of the cell, away from the endoplasmic reticulum membrane, the cells detected gravity. The statoliths of IML-1 plants will be analyzed to see if the same results are obtained.

■ Genotypic Control of Graviresponse, Cell Polarity, and Morphological Development of *Arabidopsis Thaliana* in Microgravity (SHOOTS)

Principal Investigators:
Dr. Edmund Maher
Open University of Scotland
Edinburgh, Scotland
Dr. L. Greg Briarty
University of Nottingham
Nottingham, England

The two-part SHOOTS experiment studies the response of the plant *Arabidopsis thaliana*, commonly known as thale cress, to microgravity. One of the strains of this species, the wild type, is gravitropic; its roots grow down and its shoots grow up. Another strain, aux-1, is an agravitropic mutant; its roots and shoots grow in any direction.

Both experiments study the same plant specimens. One investigates how statocytes, sensors in the plant's root tips, develop in microgravity. This experiment may show why the agravitropic mutants differ from the wild-type strain and answer questions about how plants respond to gravity. The other experiment focuses on how microgravity affects the plant's cotyledons, the parts of the seed that differentiate into the first leaf or pair of leaves. The development of statocytes in the plant's stem, called the hypocotyl, is also studied.

The seeds are germinated and grown in space and then photographed and fixed for postflight studies. Scientists hope to learn whether the wild-type plant mimics the growth of the agravitropic mutant strain in microgravity and whether the mutant continues its erratic growth patterns.

■ Effect of Microgravity Environment on Cell Wall Regeneration, Cell Divisions, Growth, and Differentiation of Plants from Protoplasts (PROTO)

Principal Investigator: Dr. Ole Rasmussen
Institute of Molecular Biology and
Plant Physiology
University of Aarhus
Aarhus, Denmark

Protoplasts are plant cells in which the cell walls have been removed by enzymatic treatment. After cell wall removal, only a thin membrane surrounds the cell, and it behaves more or less like an animal cell. Protoplasts contain all the genetic information needed for a plant to develop to maturity.

In this experiment, investigators use protoplasts from carrots (*Daucus carota*) and a fodder plant, rape (*Brassica napus*), to study the effects of microgravity on cell wall regeneration, cell division, growth, and differentiation. Before the mission, plant cells are specially prepared to make them into protoplasts which are grown in space. Periodically during the mission, a culture from each gravity environment is analyzed under the light microscope in the glovebox and photographed to determine whether the cell walls are reforming and whether the cells are dividing. These samples are then preserved and stored in the cooler for postflight analysis.

Some samples grow throughout the mission. After return to Earth, these cultures grow to maturity. The plants that develop from the 0-g and 1-g centrifuge cultures are then compared with one another and with plants grown from protoplasts that developed on the ground. The differences between the three sets of plants will further scientific understanding of gravity's role in plant growth and development. This knowledge is essential if plants are to be cultured in space to produce food, enzymes, hormones, and other products.

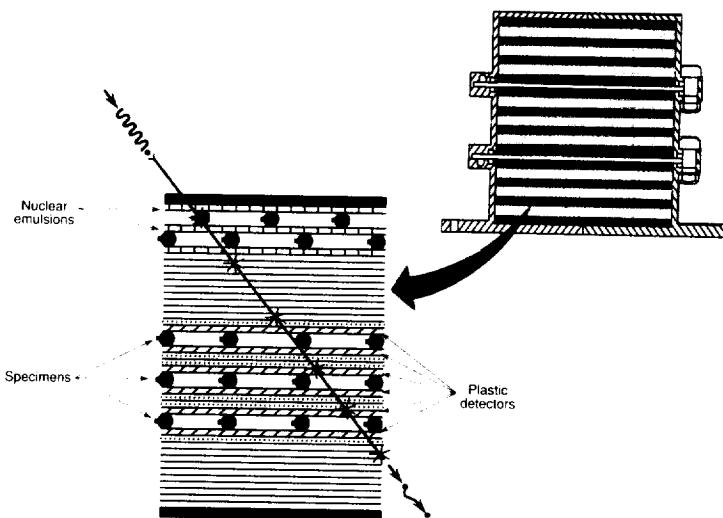
B iostack

- Provided by: DLR
- Principal Investigator: Dr. H. Buecker
Institute for Flight Medicine, DLR
Cologne, Federal Republic of Germany

Galactic particles of high atomic number and high energy can penetrate spacecraft and may damage or destroy living cells. The Biostack data will be used to calculate the potential hazards of cosmic rays to humans and biological experiments during spaceflight. Parts of the Shuttle that are particularly vulnerable to radiation will be identified so that better radiation protection can be developed for those areas. Additionally, the science of radiation biology will benefit from a better understanding of the action of these particles on biological matter.

Experiments conducted during the Apollo 16 and 17, Apollo-Soyuz, and Spacelab 1 missions demonstrated that very high local concentrations of absorbed energy delivered by single particles can have serious biological effects on an organism and that the seriousness of that damage is related to the organism's ability to repair or replace affected cells. The Biostack investigation builds on the results of these earlier investigations, using advanced methods of dosimetry and different biological samples and detectors to determine the effects of single particles on individual organisms. Four Biostack packages, located in a Spacelab rack and under the floor, measure radiation doses in different areas of the laboratory.

Single layers of bacteria and fungus spores (*Bacillus subtilis*, *Saccharomyces cerevisiae*, and *Sordaria fimicula*), thale cress seeds (*Arabidopsis thaliana*), and shrimp eggs (*Artemia salina*) are attached to sheets of nuclear emulsion and plastic radiation detectors. The sheets and specimens are sandwiched together in stacks and placed in the four sealed, aluminum Biostack containers. This arrangement guarantees that when a particle enters Biostack and passes through the layers, it will penetrate the biological samples and detectors alternately. After the mission, investigators will be able to plot the trajectory of each particle, determine its energy and where it struck a biological layer, and correlate any damage to the energy of the responsible particle. Scientists are particularly interested in genetic mutations induced by radiation and in changes to an organism's development, its activity level, and its ability to repair damaged cells.



When cosmic particles pass through the Biostack, they deposit their high energies in layers of radiation detectors and live specimens. From this energy, scientists can determine radiation levels at particular spots in Spacelab and the potential effects of exposure to radiation in space.

Radiation Monitoring Container Device

- Provided by: NASDA
- Principal Investigator: Dr. S. Nagaoka
National Space Development Agency of Japan
Tokyo, Japan

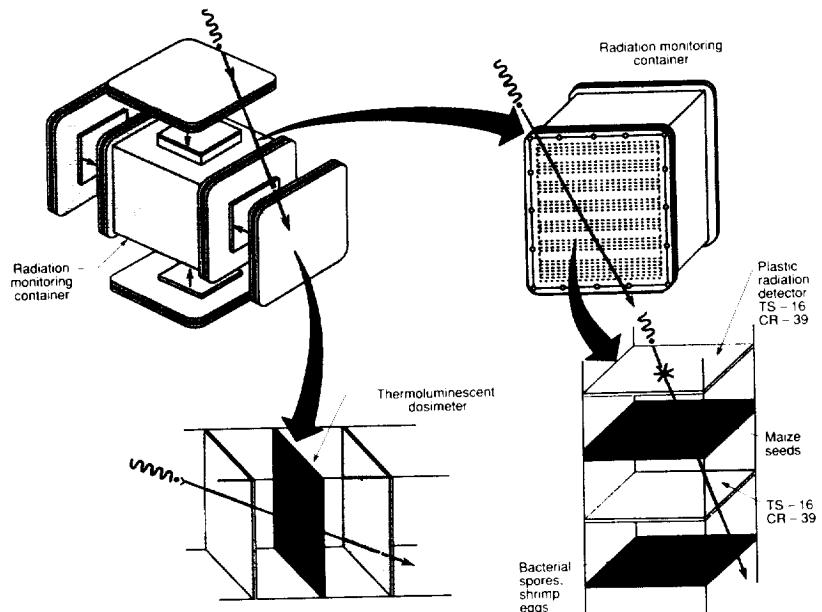
The investigation measures radiation levels inside the Shuttle and studies the effects of cosmic radiation on biological specimens to improve basic understanding of radiation biology. The data gathered will be used to develop a sensitive solid-state nuclear detector for future spaceflights.

In the Radiation Monitoring Container, layers of cosmic ray detectors and bacteria spores (*Bacillus subtilis*), maize seeds (*Zea mays*), and shrimp eggs (*Artemia salina*) are sandwiched together and enclosed on all sides by dosimeters, gauges that measure radiation doses. The radiation detectors are sheets of plastic materials (TS 16 and CR 39) that record the tracks of cosmic rays three dimensionally. The dosimeters are made of lithium fluoride and magnesium-silica-terbium, which are thermoluminescent materials. When moderately heated after exposure to radiation, these materials emit visible light proportional to the dose of radiation received.

The experiment in its box-like container is mounted on the aft end cone of the Spacelab, an area where radiation shielding is somewhat lower than in other locations. The specimens in the device are exposed to cosmic radiation throughout the IML-1 mission.

After the mission, the specimens and radiation detectors are analyzed. First, the plastic detectors are treated chemically to reveal the three-dimensional radiation tracks, called etch pits. The physical characteristics of the radiation, such as incident angle, energy, and type of cosmic radiation, determine the geometric properties of the etch pits. Next, the three-dimensional trajectories are analyzed by a computerized microscopic image handler and tracked through the layers of detector sheets and specimens. In this manner, scientists can determine which specimens were hit by high-energy radiation and the dose of radiation each received.

The specimens are examined by biological and biochemical methods to identify the effects of radiation on development, sporulation, germination, and hatching. Cells, organs, and individual organisms are observed for evidence of genetic mutation. An experiment conducted on the ground during the mission replicates the in-flight science to provide a control.



The Radiation Monitoring Container measures high-energy radiation levels in Spacelab. The information it yields will influence the design of future solid-state nuclear detectors.

Organic Crystal Growth Facility (OCGF): a two-chamber facility used to grow large, high-quality superconductor crystals. The facility is constructed to test the effectiveness of an epoxy cushioning material designed to damp accelerations that disturb crystal growth.

6

Experiment Stowage Containers: areas where experiment equipment and samples are stored.

Mental Workload and Performance Experiment (MWPE): an adjustable work surface and a portable computer used by crew members to determine the type of work area and operations that are comfortable and efficient in a weightless environment.

8

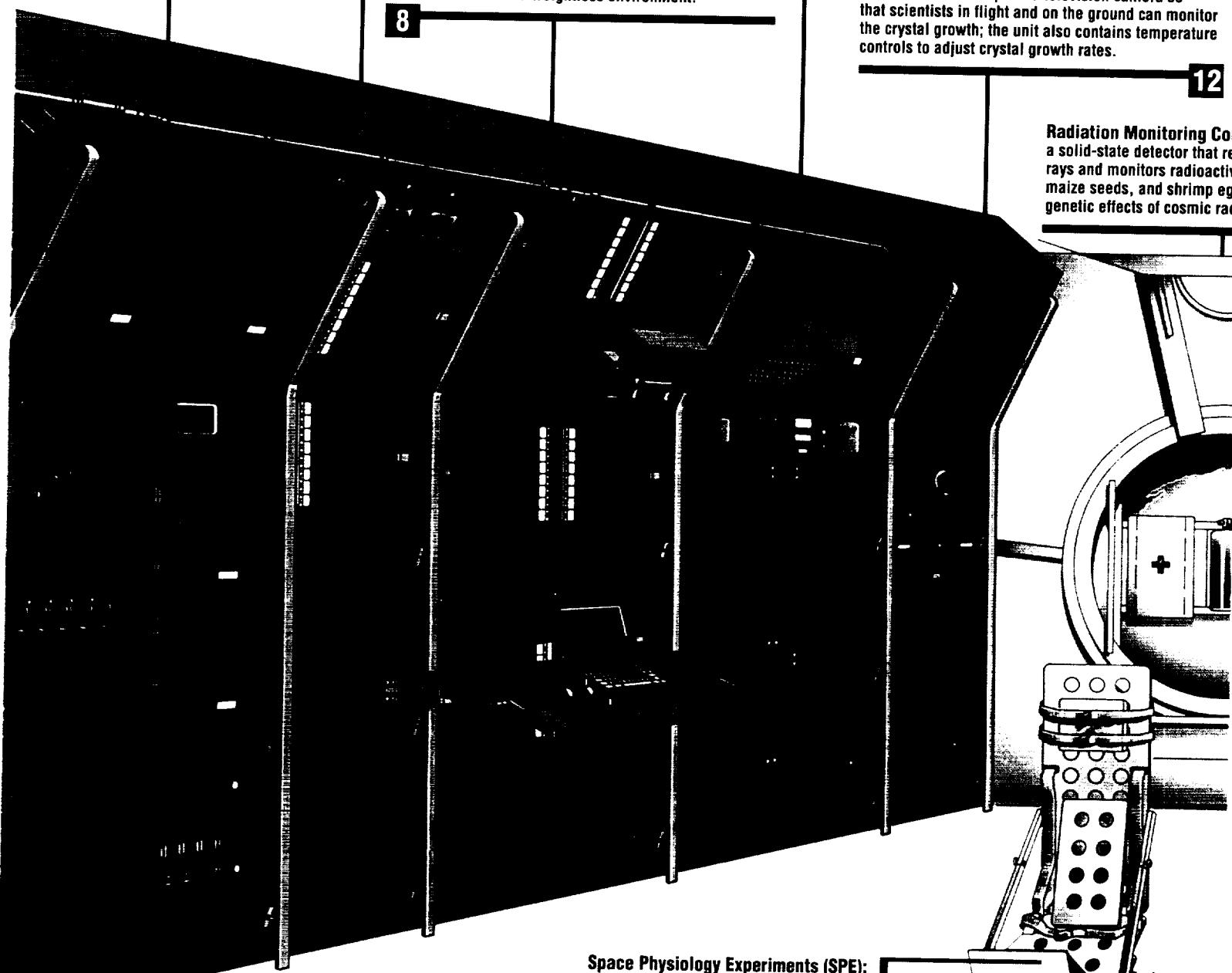
Fluids Experiment System (FES): a facility that supports experiments to grow crystals from solution and solidify metal-modeling salts. A special laser diagnostic technique records the experiments, holograms are made for postflight analysis, and video is used to view the samples in space and on the ground.

10

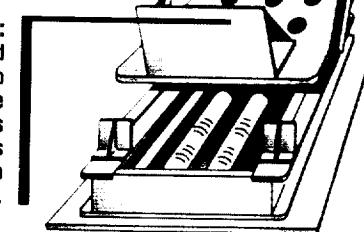
Vapor Crystal Growth System (VCGS): a facility that supports the growth of large, single crystals of mercury iodide from vapor. The system includes a microscope and television camera so that scientists in flight and on the ground can monitor the crystal growth; the unit also contains temperature controls to adjust crystal growth rates.

12

Radiation Monitoring Container: a solid-state detector that records gamma rays and monitors radioactive materials such as maize seeds, and shrimp eggs to study the genetic effects of cosmic radiation.



Space Physiology Experiments (SPE): a collection of experiments that includes a sled used to study the adaptation of the human nervous system to weightlessness. Other equipment is for studies of eye oscillations indicative of vestibular activity, adaptations of the cardiovascular system, physiological changes in the spine to analyze the causes of back pain in astronauts, and the separation of biological materials.



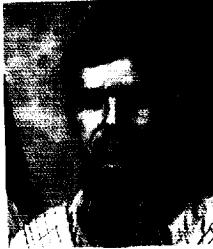
Space Shuttle uses a pressurized Spacelab module containing computers, work areas, instruments, and life support systems.

FOLDOUT FRAME 2



THE CREW

The IML-1 crew is made up of seven people: a commander, a pilot, three mission specialists, and two payload specialists. While working together as a flight team, the crew members have different roles and responsibilities. The operation of the Shuttle is the primary responsibility of the orbiter crew—the commander, pilot, and a mission specialist—who are members of the NASA astronaut corps. Science investigations are conducted by the payload crew, comprising payload specialists and mission specialists. Payload specialists are scientists who have taken temporary leave from their laboratories to participate in a Shuttle mission. Mission specialists are members of the NASA astronaut corps with specialized training in one or more science disciplines. Two alternate payload specialists support the mission from the ground at the Payload Operations Control Center.



COMMANDER

Ronald J. Grabe: A graduate of the Air Force Academy, Col. Grabe (USAF) earned a B.S. in engineering science and studied aeronautics in West Germany as a Fulbright Scholar. After completing pilot training, he was assigned as an F-100 pilot in Vietnam where he flew 200 combat missions. Col. Grabe later attended the USAF Test Pilot School and, after graduating, served as a test pilot and instructor. In 1980, he was selected as an astronaut. Since then, Col. Grabe has been involved in testing the shuttle guidance, navigation, and control system and in developing Space Station Freedom.

Shuttle guidance, navigation, and control system and in developing Space Station Freedom. He was the pilot for STS 51-J (October 1985) and STS-30 (May 1989). IML-1 is his third Shuttle mission.



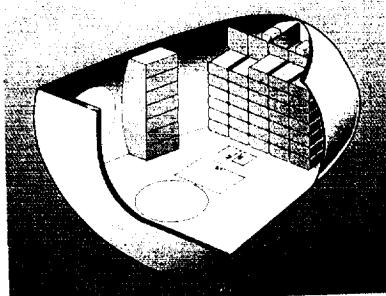
PILOT

Stephen S. Oswald: After graduating from the U.S. Naval Academy with a B.S. in aerospace engineering, Oswald was appointed Naval Aviator and flew a Corsair II aboard the USS Midway in the Western Pacific and Indian Oceans. He attended U.S. Naval Test Pilot School and remained at the Naval Air Test Center after graduation to conduct flight tests in various tactical aircraft. After leaving the Navy, Oswald became an aerospace engineer and instructor pilot for NASA. He was selected as an astronaut in 1985. His assignments have included serving as flight crew representative to the Kennedy Space Center, testing flight software, and working with the Marshall Space Flight Center on the redesigned solid rocket booster. IML-1 is his first Shuttle mission.



MISSION SPECIALIST

William F. Readdy: Readdy graduated from the U.S. Naval Academy with a B.S. in aerospace engineering and served as a Naval Aviator aboard the USS Forrestal and USS Coral Sea in the North Atlantic and Mediterranean. After completing studies at the U.S. Naval Test Pilot School, he was named project pilot for a number of aircraft test programs and also worked as an instructor. Readdy joined NASA in 1986 as an aerospace engineer and instructor pilot and was selected as an astronaut in 1987. Since then, he has served on the Orbiter Project Staff as flight crew representative. On IML-1, Readdy serves as the flight engineer for ascent and entry and as a Shuttle pilot. IML-1 is his first Shuttle mission.



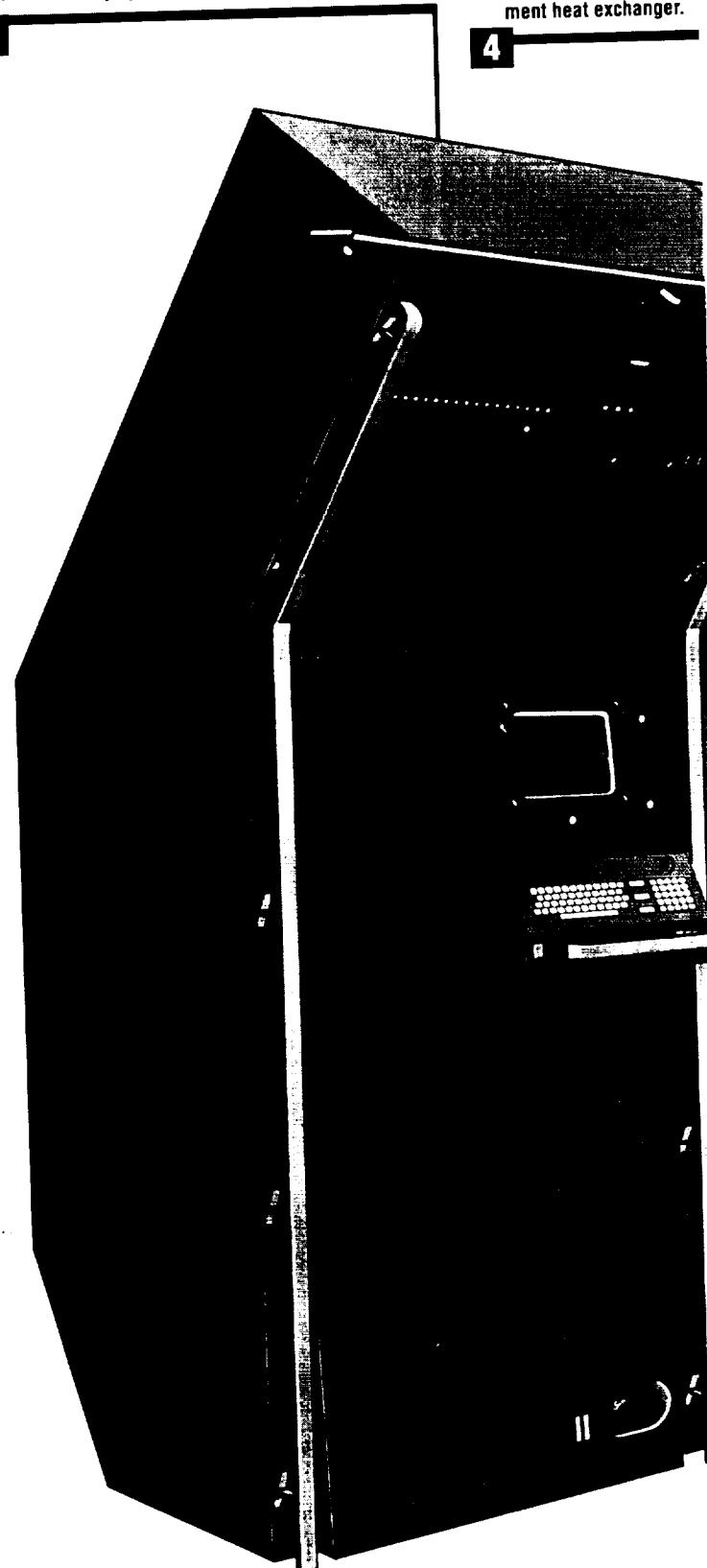
Middeck: The middeck is connected to Spacelab by a tunnel. Lockers in this part of the Shuttle carry additional experiment equipment including the Protein Crystal Growth (PCG) experiment.

PCG: 120 crystal growth chambers in two temperature-controlled refrigerator/incubator modules for growing protein crystals that may yield information vital to bioengineering and pharmaceutical studies.

Spacelab Control Center: the computer center for managing data and for operating laboratory systems and certain experiments. Some of these activities are carried out by the crew; others are performed automatically by computers.

2

4



Inside Spacelab: The IML-1 miss

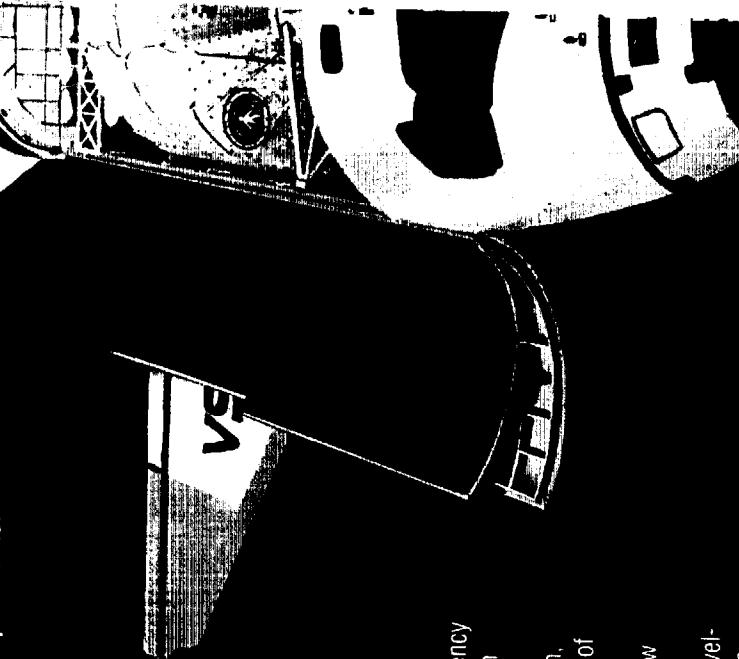
AN INTERNATIONAL

MISSION TO SPACELAB. To conduct science and technology investigations that require the low-gravity environment of space, with emphasis on experiments that study the effects of microgravity on material processes and living organisms.



On-Orbit Operations: Gravity Gradient Attitude

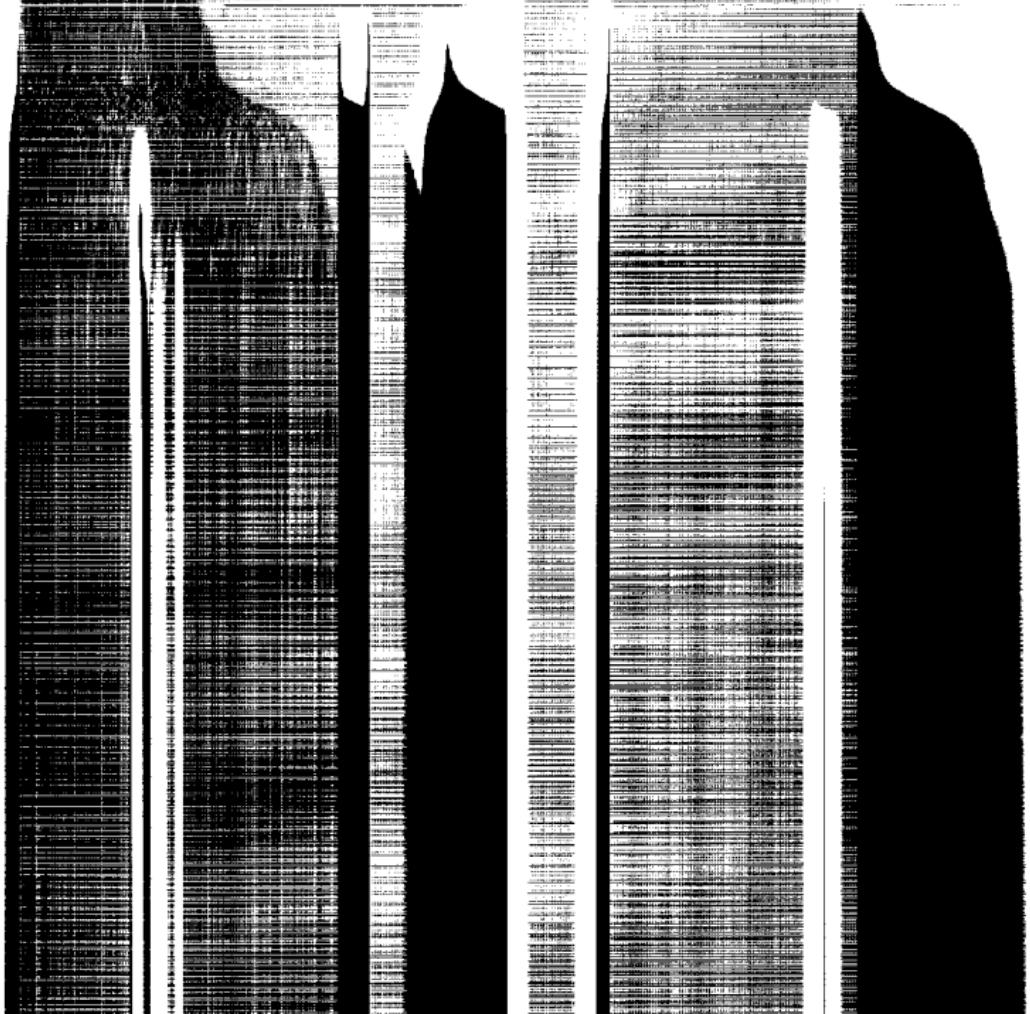
In addition to a low-gravity environment, many of the IML-1 experiments require a very smooth ride through space so that their delicate operations are not disturbed. The best way to maintain a stable drift is to keep the tail of the Shuttle pointed toward Earth. In this orientation, called a gravity gradient attitude, the vehicle's position is maintained primarily by natural forces. This reduces the need for orbiter thruster firings that disturb acceleration-sensitive experiments.



The National Aeronautics and Space Administration (NASA) is the United States agency dedicated to research and development in space science and technology. NASA oversees the IML program and provides transportation for the experiments on the Space Shuttle and Spacelab. The agency's headquarters are located in Washington, D.C.



The Canadian Space Agency (CSA) was established in 1989 to oversee the Canadian Space Program, which was formerly part of the National Research Council. Through this new agency, Canada will continue its research and development activities in space science, technology, and operations. CSA headquarters are in Montreal, Quebec, Canada. The agency is headquartered in Paris, France.





A ruby-red crystal about the size of a sugar cube glitters inside a small heated chamber. Almost 170 miles away on Earth, a scientist measures the crystal on a video screen.

- ▶ *"Payload specialist 1, this is Marshall operations," a person in the ground control center says. "We are putting the principal investigator on."*
- ▶ *"That's a nice size crystal," the investigator tells his colleague in space. "It appears to be growing relatively fast. Can you take a closer look at it for us? We thought there might be a small defect forming on the C face of the crystal. Can you see it through the window?"*
- ▶ *"Yes, it looks like it has some long linear growth that is parallel to an edge."*
- ▶ *"It appears that we may be at a critical growth rate. Let's watch it closely. We may need to make some adjustments to get rid of the defect."*

In the Shuttle middeck, another crew member inspects protein crystals growing in small chambers and reports on their progress to the principal investigator team on the ground.

- ▶ *"There are thin, white crystals that look like threads in the first two chambers. The next two chambers have the same kind of crystals, but there aren't as many of them."*

The next shift is devoted to studying how fluids behave in weightlessness as they solidify to form crystals and metal alloys.

- ▶ *"How does the crystal look?" the principal investigator on the ground asks the mission specialist.*
- ▶ *"The seed crystal is just as pretty as it could possibly look. In other words, this time, it is not growing like a table top. It is growing straight out as planned."*
- ▶ *"Oh, that's a good view," the investigator comments on the new video of the crystal downlinked to the ground control center. "When you looked inside the optical bench, did you see any sign of small crystals forming in any part of the cell?"*
- ▶ *"None whatsoever. The fluid looked clear."*
- ▶ *"That's a very good sign. We're happy about it."*

Biostack: sealed detectors that will be used to determine the effects of cosmic radiation on biological samples and to develop shielding devices.

Cryostat: a facility that supports protein crystal growth experiments in two temperature environments.

Critical Point Facility (CPF): a temperature-controlled facility that supports the investigation of fluids as they undergo phase transitions from liquids to gases.

9

Mercury Iodide Crystal Growth (MICG): a furnace for growing mercury iodide crystals. Single crystals are formed by vapor transport in quartz ampoules.

IMAX Camera: a 70-mm high-fidelity camera that produces large-format film footage. The IMAX is being used to make movies in space.

11

Refrigeration and Cooling Device (RMCD): provides high-energy cosmic ray levels. Bacteria spores, are analyzed to determine mutation.

Gravitational Plant Physiology Facility (GPPF): equipment used to investigate how plants respond to gravity and light. Seedlings are placed in centrifuges to expose them to varying g-forces and in chambers to expose them to flashes of light. Plant growth behavior is recorded with three infrared-sensitive video cameras operating in a time-lapse mode.

Microgravity Vestibular Investigations Experiment Control and Data Interface (ECDI): the experiment control center for the Microgravity Vestibular Investigations. A crew member controls the motion of the swiveling chair from this facility which also records the sensory reactions of the subject. The control center also provides data handling and transmission capabilities.

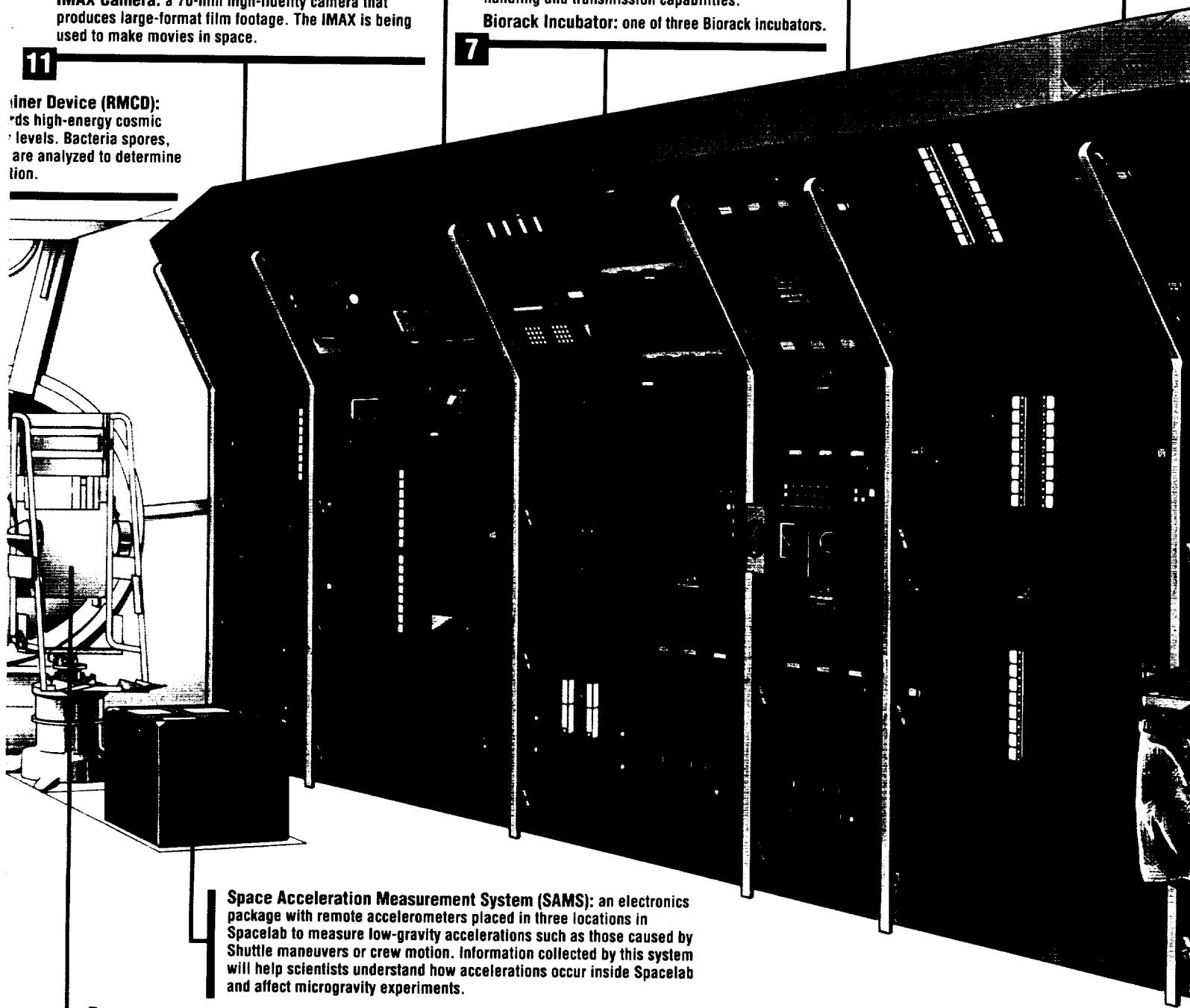
Biorack Incubator: one of three Biorack incubators.

7

Biorack: a multipurpose facility that supports investigations into the effects of microgravity and cosmic radiation on cells, tissues, plants, bacteria, insects, and other biological samples. The IML-1 Biorack system contains three incubators, a glovebox, and a cooler/freezer unit that allow crew members to grow, handle, and preserve hundreds of biological samples for further study on Earth.

5

Experiment areas where and sample



Space Acceleration Measurement System (SAMS): an electronics package with remote accelerometers placed in three locations in Spacelab to measure low-gravity accelerations such as those caused by Shuttle maneuvers or crew motion. Information collected by this system will help scientists understand how accelerations occur inside Spacelab and affect microgravity experiments.

Microgravity Vestibular Investigations (MVI): a swiveling chair and a special helmet equipped with a video camera for conducting vestibular (inner ear) investigations that support research into human physiological adaptation to the space environment. Eye motions, head movements, and vestibular reactions are monitored.

ent racks for experiments, and utilities. Most experiment facilities are mounted in

FOLDOUT FRAME

ON A MISSION

Science Applications - Major microgravity research because of the changes in the structures of materials in the environment can be determined by examining how they have grown in microgravity, advances can be made to improve the treatment of human diseases. Space investigations of the effects of diseases may lead to a remedy for the space motion sickness suffered by astronauts. Electronic materials research in space may help us refine processes and make better products, such as computers, lasers, and other high-tech devices. Basic science investigations in biology and physics will increase our understanding of fundamental processes.

Participating Agencies: Through six international space science research organizations, more than 200 scientists from 13 countries are collaborating with NASA on the IML-1 mission to provide the worldwide science community with a variety of complementary facilities and experiments.

Mission Facts

Launch Site	Kennedy Space Center, Florida
Flight Number	STS-42
Altitude	160 nautical miles (296 kilometers)
Orbital Path	Circular
Inclination	57 degrees
Mission Attitude	Gravity gradient
Mission Duration	7 days
Crew Size	7
Payload	Materials science and life sciences experiments
Payload Operations	Around the clock



DARA
DEUTSCHE AGENTUR FÜR
RAUMFAHRTGELEGENHEITEN
(DARA) GMBH

The French National Center for Space Studies (CNES) supports a comprehensive space science research program carried out by the National Center for Scientific Research, universities, and other organizations in France. CNES Headquarters are located in Paris, France.

The German Space Agency (DARA) was established in 1989 as a central organization to coordinate all space activities of the Federal Republic of Germany. DARA Headquarters are in Bonn, West Germany. The German Aerospace Research Establishment (DLR), the Federal Republic's largest organization devoted to engineering sciences, is responsible for research and hardware development.

宇宙開発事業団

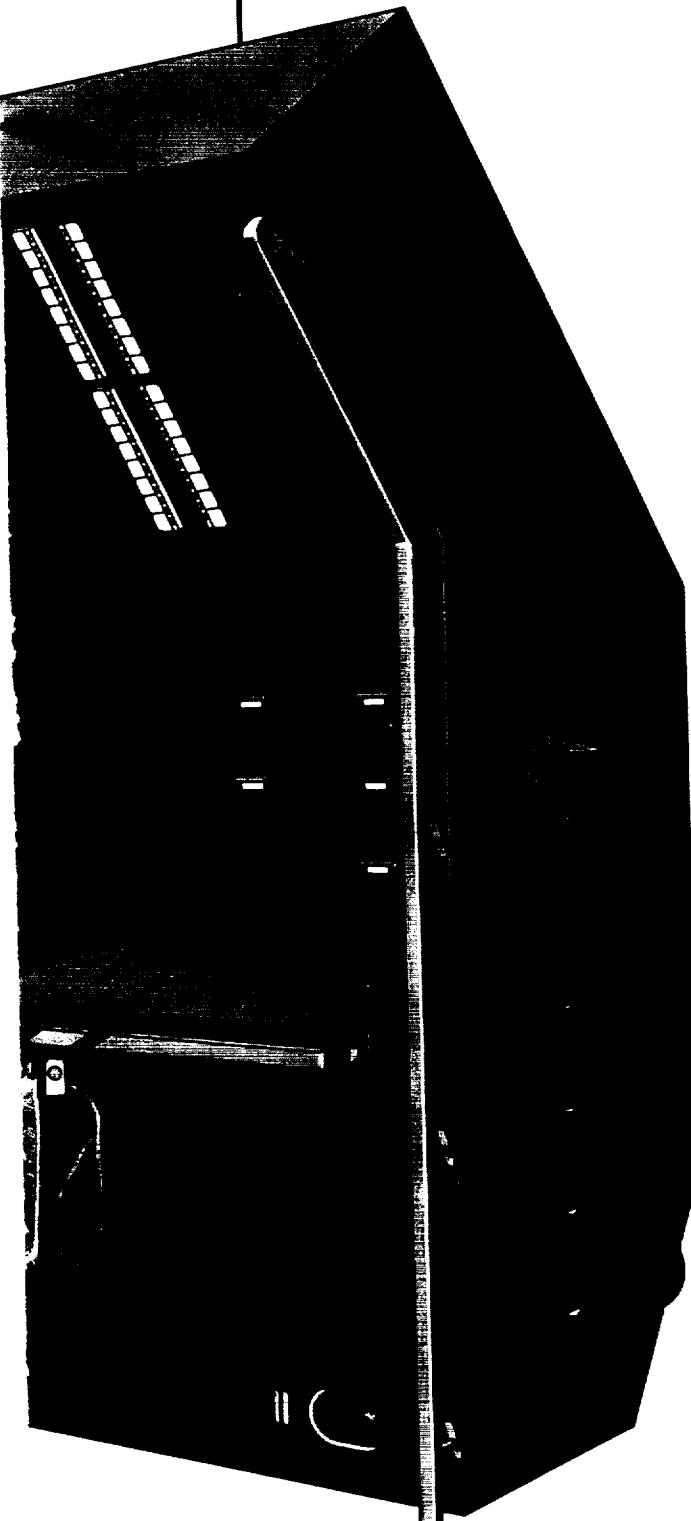
The National Space Development Agency of Japan (NASDA), headquartered in Tokyo, Japan, is responsible for many of Japan's space activities. The organization explores the practical applications of the space environment and is primarily involved in microgravity research and satellite development.

PAYOUT SPECIALISTS

Workbench: an area where crew members record data in their logs or carry out general activities. The workbench includes stowage containers, tools, and small equipment.

Stowage Containers: experiment equipment are stored.

3



Roberta L. Bondar: A member of the Canadian Astronaut Program since 1983, Dr. Bondar has a Ph.D. in neurobiology, an M.D., and is a Fellow of The Royal College of Physicians and Surgeons of Canada in neurology with subspecialty training in neuro-ophthalmology. Dr. Bondar is a principal investigator on taste experiments flown on the Shuttle and is also investigating cerebral blood flow velocity during weightlessness. Dr. Bondar has served as a representative of Canada to encourage and coordinate international collaboration in life sciences research in space.



Ulrich D. Merbold: Dr. Merbold, a specialist in crystal lattice defects and low-temperature physics, holds a Ph.D. in solid-state physics and has been involved in research for more than a decade. He was a payload specialist on the first Spacelab mission (STS-9 in 1983), during which 72 experiments from 8 science disciplines, including materials science, fluid physics, and life sciences, were performed. Dr. Merbold also served as an alternate payload specialist on Spacelab D1 and is a principal investigator for a materials science experiment scheduled to fly on the upcoming Spacelab D2 mission. In 1987, Dr. Merbold was appointed head of the astronaut office of the West German Research and Development Institute for Air- and Spacecraft (DLR).

ALTERNATE PAYLOAD SPECIALISTS



Roger K. Crouch: Dr. Crouch has been a principal investigator in NASA's Microgravity Science and Applications Division (MSAD) for over 10 years. His experiment involves the directional solidification of compound semiconductors. [A preliminary version of this investigation flew on the Spacelab D1 mission (STS-61A, November 1985).] Dr. Crouch became the MSAD chief scientist in 1985 and is well-versed in the IML-1 materials science experiments. He has a Ph.D. in physics and carried out research at Langley Research Center in Hampton, Virginia, for over 20 years.



Kenneth E. Money: Dr. Money is a Canadian scientist with extensive experience in research involving the vestibular system, motion sickness, decompression sickness, and histology. He has a Ph.D. in physiology and is an associate professor at the University of Toronto. Dr. Money is also a pilot with experience in bush planes, transports, fighters, and helicopters. He has worked with NASA in several capacities and is a co-investigator in the vestibular experiments on five Shuttle flights. Dr. Money's work has resulted in many important advances in alleviating the problems of motion sickness and pilot disorientation in flight.

MISSION SPECIALISTS



Manley Lanier "Sonny" Carter: Capt. Carter (USN) has an M.D. and is a graduate of the U.S. Navy Flight Surgeon School. He is also a Naval Aviator and has completed U.S. Navy Fighter Weapons School (TOPGUN) and U.S. Naval Test Pilot School. Capt. Carter has served as both the senior medical officer on the USS *Forrestal* and as a fighter pilot with Marine Fighter Attack Squadrons. He was selected as an astronaut in 1984 and served as a mission specialist on STS-33 (November 1989), a classified Department of Defense mission. IML-1 will be his second Shuttle flight.



Norman E. Thagard: Dr. Thagard, who has an M.D., is a researcher and teacher and has designed several electronic instruments and small computers. He was selected as an astronaut in 1978, and during his first Shuttle flight (STS-7, June 1983), he operated the Remote Manipulator System, deployed satellites, and conducted experiments that studied human adaptation to space. He served as a mission specialist on the crew of Spacelab 3 (STS 51-B, April 1985) and conducted life sciences experiments. On STS-30 (May 1989), he helped deploy the Magellan Venus exploration spacecraft. IML-1 is Dr. Thagard's fourth Shuttle mission.

12 racks in this laboratory module.

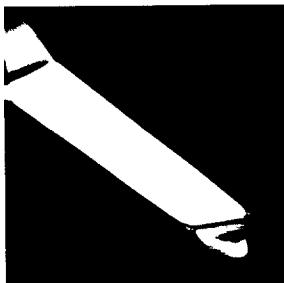
FOLDOUT FRAME

IML-1 Materials Science Experiments

To produce a more nearly perfect crystal or a new material requires exactly the right steps, and scientists are just beginning to characterize processes in weightlessness that affect materials production in space. Brief experiments on Earth inside airplanes, rockets, and drop tubes, in addition to a few longer experiments in space, suggest that materials do act differently in microgravity. The effects of gravity are virtually cancelled as the Space Shuttle orbits Earth, and inside Spacelab, scientists have the opportunity to do longer, more controlled experiments in low-gravity.

Gravity-related effects such as convection, buoyancy, and sedimentation limit the perfection of some materials. Convective flow occurs in almost every Earth-based liquid or gas in which there is a temperature difference. These flows are responsible for making warm air rise to the ceiling of a room while cool air lingers near the floor. Because almost all fluids or vapors expand when heated, even the slightest temperature change causes the warmer part of the substance to become less dense. In 1-g, the less dense fluid or vapor weighs less, and it rises while the cooler part of the substance moves down to replace it. This results in convective flow as heat is transferred by the movement of molecules. In microgravity, transport of vapor and fluid should occur by diffusion, a movement of molecules from regions of high concentration to regions of low concentration. Scientists are able to control diffusion more easily than convection and thus may be able to produce better materials in space where diffusion dominates over convection.

On Earth, buoyancy and sedimentation also hinder some materials processing: heavy materials settle instead of mixing with other lighter materials. Buoyancy causes the lighter part of a fluid mixture to rise, initiating convective flows, and sedimentation causes heavy substances to settle below lighter substances. Ice floats on top of a lake because it is buoyant, while mud settles on the bottom. These gravity-related processes



Several crystals, such as these grown on previous flights, will be grown on IML-1:
A - Protein crystal; B - Triglycine sulfate crystal; C - Mercury iodide crystal.

may keep metals from combining to form uniform alloys. Since buoyancy and sedimentation are eliminated in weightlessness, solids, liquids, and gases can remain in suspension. This may make it possible not only to create new alloys and composites but also to examine fundamental properties of fluid interactions.

IML flights offer investigators a place to process materials in microgravity for at least 7 days. Longer processing times are important for many solidification experiments, especially crystal growth. For the IML-1 mission, investigators grow several types of crystals by various techniques. Pure, nearly perfect crystals are required in computers, lasers, and numerous other optical and electrical devices. Other experiments examine fluid processes that are masked or distorted by gravity. Nearly every physical science depends on an understanding of these processes, and this basic knowledge is needed to

produce the next generation of high-strength metals essential to power generators, propulsion systems, airplanes, and spacecraft.

To do controlled experiments in space, we must also identify other disturbances that might disrupt sensitive experiments. A special accelerometer system carefully measures the accelerations inside Spacelab; this allows investigators to trace any vibrations from Shuttle engine firings, crew motions, or other instruments that cause convection and interfere with experiments.

Half of the IML-1 materials science experiments have flown on previous missions, and this reflight opportunity gives scientists a chance to build upon previous results and apply lessons learned to improve experiment techniques. IML-1 also provides valuable research opportunities to U.S. scientists and their international partners who will also work with them aboard Space Station Freedom.

Materials Science Experiment Hardware

Critical Point Facility	ESA
Cryostat	DLR
Fluids Experiment System	NASA
Mercury Iodide Crystal Growth	CNES
Organic Crystal Growth Facility	NASDA
Protein Crystal Growth	NASA
Vapor Crystal Growth System	NASA

The following descriptions detail materials science experiments that have been scheduled for the IML-1 mission and supplementary science that will be done if time permits.

Space Acceleration Measurement System (SAMS)

Materials science experiments require a stable, very low-gravity environment to yield the most accurate data. Accelerations, such as Shuttle thruster firings or crew activity, mimic gravity and can have the same damaging effect on these investigations.

Life sciences experiments studying gravity effects are also vulnerable to accelerations. On IML-1, the Space Acceleration

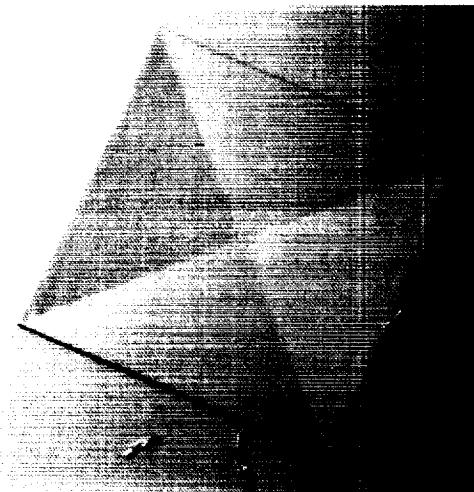
Measurement System, developed by NASA's Lewis Research Center in Cleveland, Ohio, measures and records low-g accelerations so that scientists can apply this information when analyzing the data collected on the mission. The system accommodates three accelerometers that can be placed with the experiment hardware. These remote sensors, which are connected electrically to the main unit, signal the unit's data acquisition system in response to accelerations they detect at the site of the experiment apparatus. These signals are then amplified, filtered, converted to digital data, transferred to a computer, and stored for postflight analysis.

During IML-1, the Space Acceleration Measurement System will use two types of accelerometers: a low-resolution unit that can detect accelerations as low as 10^{-6} -g and a high-resolution unit that can detect accelerations as low as 10^{-8} -g. One low-resolution device is located under the Microgravity Vestibular Investigations' rotating chair. A second low-resolution sensor is located on the Spacelab rack containing the Fluids Experiment System, a facility in which very sensitive materials science experiments are performed. The high-resolution accelerometer is located inside the Fluids Experiment System rack near the experiment sample. Scientists will correlate the acceleration measurement system's data with the experiment results from this investigation to better understand how accelerations occur inside Spacelab and how they affect microgravity research.

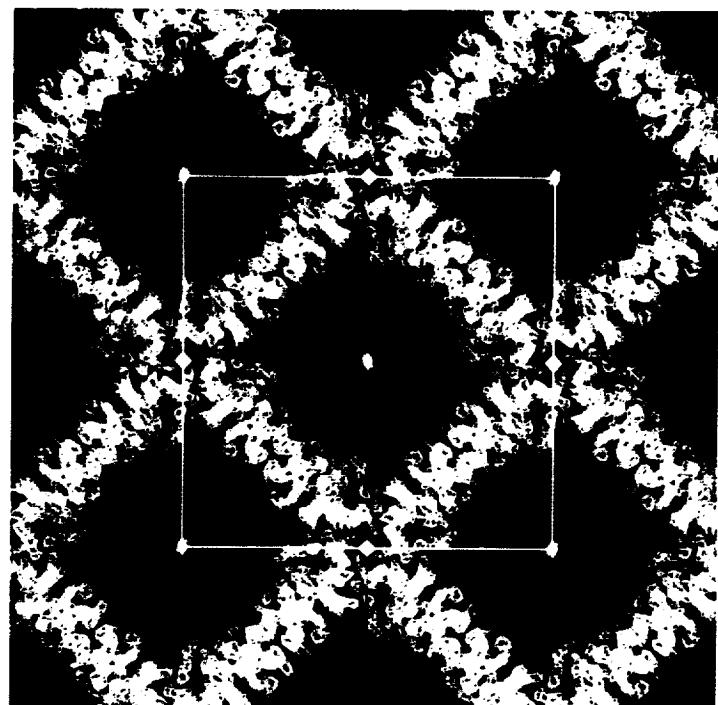
Proteins

Proteins are essential to all life. Some — the hormones and enzymes — control and protect; without them, animals could not manufacture antibodies to fight disease, regulate their bodies, extract nourishment from food, grow, or reproduce. Others are important to the formation and maintenance of skin, muscles, tendons, bones, and hair. Plant proteins have similar protective and structural functions.

Proteins are large, complex molecules made up of well-defined groups of amino acids. The body's genetic material, much like a blueprint, contains the chemical construction plans for thousands of proteins, defining the specific amino acid building blocks, their exact number, and their very concise arrangement. This chemical structure dictates the protein's role and is so critical that if even one amino acid is missing from the string, out of order, or replaced by another, the protein's function may be altered or impaired. Hemoglobin, for



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example, is the protein in red blood cells of mammals that makes it possible for the blood to carry oxygen from the lungs to other parts of the body. When only one amino acid (glutamic acid) is replaced by another (valine) in the hemoglobin molecule, the shape of the red blood cells is so distorted that the cells cannot transport oxygen efficiently, a condition known as sickle cell anemia.

Scientists have long sought to define the architectural plans of many plant and animal proteins. If these can be determined, it may be possible to design drugs that enhance or inhibit protein behavior, an important advance to cancer, immune system, and agricultural genetics research. Individual protein molecules are too small for analysis, so investigators grow protein crystals to determine their three-dimensional anatomy, but the internal order of Earth-grown crystals tends to be distorted by convection that gravity causes in the growth solutions.

Two IML-1 experiments, both of which have been flown before, grow protein crystals: the Protein Crystal Growth experiment, which

uses the vapor diffusion process, and the Cryostat, which uses the liquid diffusion process. For the Protein Crystal Growth experiment, many types of crystals are grown under different conditions. The Cryostat grows several types of protein crystals under different modes, one that varies temperature and one that varies the concentration of solutions used to grow the crystals.

Both experiments analyze the crystals using a technique known as X-ray crystallography. The crystals are bombarded with X-rays, which are diffracted by the crystalline structure and produce patterns that can be observed on a photographic plate or electronic detector. The patterns resemble a symmetric array of spots and suggest the geometry of the protein. Scientists use this technique to determine a protein's chemical architecture. With this information, they are better prepared to design chemical products to control a specific protein's function.



Human serum albumin is the most abundant plasma protein in blood and performs many functions critical to human life. One of its roles is to transport a variety of metals, fatty acids, amino acids, and hormones throughout the body. The molecule also renders many therapeutic drugs less effective. For years, scientists have been trying to determine the three-dimensional structure of the molecule to understand how it binds so many different materials and how it interacts with drugs. Analyses of a human serum albumin crystal grown on the ground (a) have produced a low-resolution picture of the molecule. X-rays diffracted by electrons in the crystal revealed a pattern (b) of channels through which solvents flow within the molecule. Using this map, scientists produced a computer image of the electron densities, which hinted at molecular shape (c). A second computer graphic (d) showed two sites (represented by red spheres) where human serum albumin binds aspirin. Space-grown crystals show promise of yielding the higher resolution needed to determine more details of the molecule's structure.

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P rotein C rystal G rowth

- Provided by: NASA
- Principal Investigator: Dr. Charles E. Bugg
University of Alabama at Birmingham
Birmingham, Alabama, USA

The IML-1 Protein Crystal Growth investigation is made up of 120 individual experiments designed for the low-gravity environment of space. Scientists hope to grow larger, less flawed crystals than those produced in 1-g.

Protein crystal experiments on Shuttle missions STS-26 in 1988 and STS-29 in 1989 produced several crystals of better quality than any grown on Earth. They were large (1 mm/0.04 in.) with nearly perfect shapes or morphologies, and the molecules within the crystals were well-ordered, meaning the crystals could be resolved better during X-ray analysis.

On STS-26, scientists grew the largest crystal of gamma-interferon, a protein that stimulates the human immune system and is used to treat certain cancers. A space-grown crystal of isocitrate lyase, a plant enzyme on which fungicides act, had distinct prisms, unlike its usual branch-like growth pattern on the ground. Another enzyme, elastase, which has been connected to the destruction of lung tissue in people with emphysema, formed the largest, most nearly perfect crystal of that enzyme ever produced. Crystals of all three proteins produced better resolution data than previous crystals. Finally, the protein canavalin from the jack bean, a plant of great nutritional value, formed single crystals rather than the crystal clusters usually produced on Earth.

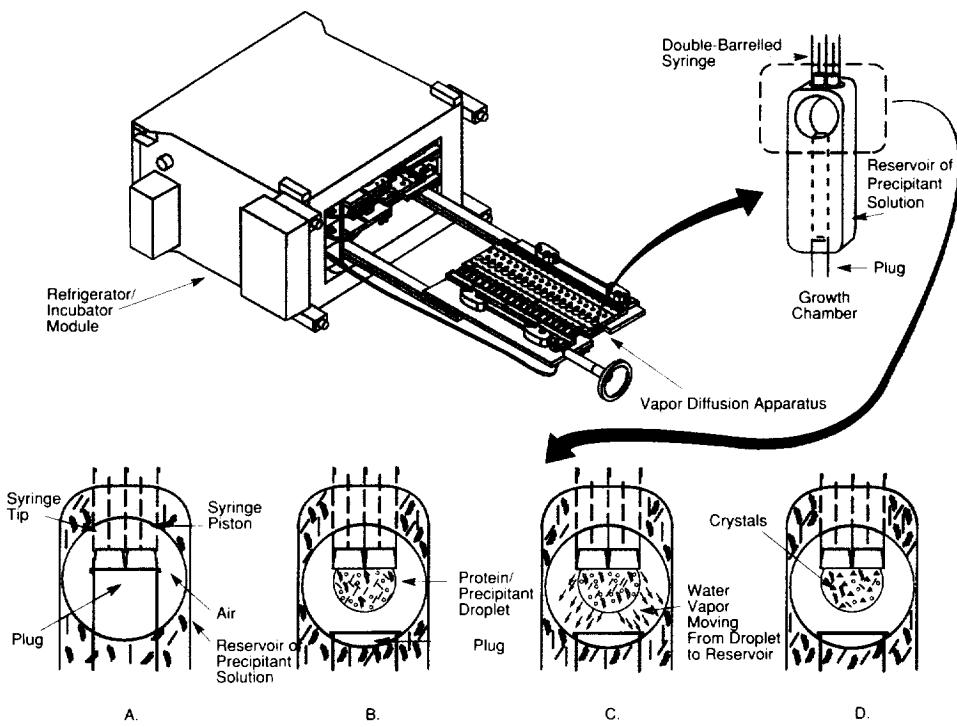
During STS-29, more high-quality gamma-interferon crystals were grown. Also on this mission, scientists first attempted to grow crystals of a virus. The satellite tobacco mosaic virus formed nearly 200 crystals with a shape not seen before. In addition, greatly improved crystals of lectin, a plant seed protein, were grown; these crystals have already been used to determine the structure of the protein.

The 120 IML-1 Protein Crystal Growth experiments, located in two Refrigerator/Incubator Modules, operate by the vapor diffusion method of crystal growth. Each of six Vapor Diffusion Apparatus trays holds 20 protein crystal growth chambers. A reservoir of a highly concentrated precipitating solution lines the wells of each chamber. A double-barrelled syringe — one barrel loaded with protein solution, the other with a low-concentration precipitating solution — protrudes into the chamber, and a region of air space separates the syringe from the reservoir. The experiment begins as the liquids from both syringe barrels are extruded and mixed, forming a drop on the syringe tip. Because the concentration of precipitating solution in the reservoir is greater than that in the droplet, water vapor moves from the droplet to the reservoir. This increases the concentrations of protein and precipitating agents in the droplet, and crystals begin to form.

The experiments start early in the mission and continue until just before the mission ends, when the droplets and any crystals they contain are drawn back into the syringe for protection during landing. After the mission, crystals are returned to the laboratory and analyzed using X-ray crystallography.



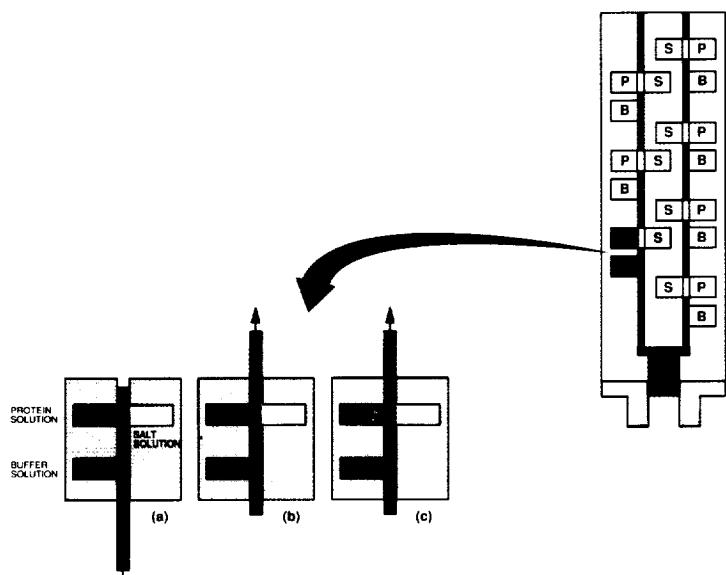
Some protein crystals grown on the ground have odd shapes that interfere with analysis. For example, crystals of isocitrate lyase, a plant enzyme targeted by fungicides, often have tree-like growths, called dendrites (a). On STS-26 (September 1988), the first distinct prisms of isocitrate lyase (b) were grown in space; over 25 crystals were produced on this mission.



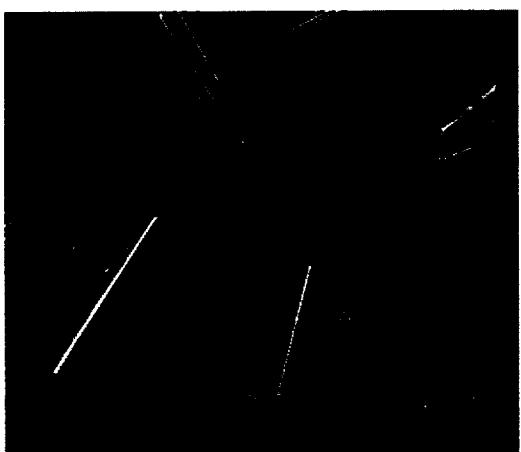
A double-barrelled syringe holds protein crystal growth materials separate before the experiment begins (a). A crew member turns one handwheel to withdraw the plug and another to activate pistons that push the two solutions out of the syringe and into an air space, where they form a hanging drop (b). During the mission, water vapor moves out of the drop and into a reservoir lining the growth chamber (c), thus increasing the concentration of precipitating solution in the droplet and stimulating protein crystal growth (d).

Cryostat

■ Provided by: DLR



One of two Cryostat sample containers (right) holds seven samples. To make crystals, protein, salt, and buffer solutions are used. Before the experiment begins (a), a barrier keeps the buffer solution from interacting with the protein and salt solutions. When the barrier is removed (b), the buffer solution brings the salt solution in contact with the protein solution. Soon, crystals form in the protein solution chamber (c).



Beta-galactosidase crystals were grown on Spacelab 1. For IML-1, scientists will try to grow higher quality crystals.

The Cryostat provides a temperature-controlled environment for growing protein crystals under two different thermal conditions. The facility has two thermostat chambers that operate in different modes: the stabilizer mode in which a constant temperature between +15 and +25 °C is maintained and the freezer mode in which temperatures can be varied from -8 to +25 °C during an experiment. A computer is preprogrammed to automatically control the temperatures of each thermostat, but crew members can reprogram the computer if necessary.

Two blocks (sample containers) are used, one for each thermal condition, and each block is divided into chambers that hold seven samples. The blocks are placed in a thermos container (dewar) kept at 0 °C and loaded in the middeck 13 hours before launch. Once in space, the crew start the Cryostat, and run it 1 hour to adjust the temperature; then they insert blocks in the Cryostat's two thermostat chambers. In about 2 hours, all the samples in each block reach the appropriate temperature, and a computer preprogrammed with the temperature profile starts the experiments automatically.

The crystals are grown by liquid diffusion for as long as possible. Each chamber is filled with a solution of salt precipitant (a substance that causes another substance to separate out as a solid from a solution) and a particular protein solution. Before the experiment begins, a barrier divides each chamber, keeping the salt precipitant and the protein from interacting. When the chambers reach the correct growth temperature, a drive mechanism moves the barrier and releases a buffer solution from another compartment. The buffer brings the salt solution in contact with the protein solution, and the salt precipitant initiates the formation of crystals in the protein solution at the end of each chamber. The temperature and time of the experiments are recorded on computer, and the payload specialist tells each investigator when the experiments begin. Near the end of the mission when the salt solutions have stabilized, the payload specialist removes the sample blocks, puts them in the middeck stowage dewars for early retrieval postflight, and deactivates the Cryostat.

After the flight, the crystals are removed and analyzed by X-ray crystallography to determine their quality and, if possible, their structures. The crystals grown in space are compared with crystals grown in a ground-based Cryostat and with proteins crystallized in other facilities.

Three principal investigators, two from the Federal Republic of Germany and one from the United States, grow different proteins in the Cryostat.

Single Crystal Growth of Beta-Galactosidase and Beta-Galactosidase/Inhibitor Complex

Principal Investigator: Dr. W. Littke

University of Freiburg, Freiburg, Federal Republic of Germany

For this investigation, the Cryostat is used in the freezer mode. The temperature starts at -4 °C and gradually increases to +20 °C. The total concentration of the salt (ammonium sulfate) in each chamber is constant.

The proteins to be crystallized are beta-galactosidase and beta-galactosidase/inhibitor complex. Beta-galactosidase is an enzyme that hydrolyzes lactose and is found in the intestines of human and animal babies as well as in *E. coli* bacteria. It is a key enzyme in modern genetics, and scientists want to determine its three-dimensional molecular structure to find out how the structure of the molecule affects its function. Beta-galactosidase was the first protein crystallized in space using the Cryostat on Spacelab 1 in 1983. The space crystals were several times larger and more perfect than those produced on the ground. However, the quantity of the crystals was limited, and scientists were not able to complete X-ray studies of the protein's structure.

Crystal Growth of the Electrogenic Membrane Protein Bacteriorhodopsin

Principal Investigator: Dr. G. Wagner

University of Giessen, Plant Biology Institute 1

Giessen, Federal Republic of Germany

This experiment uses the stabilizer mode. In this mode, the temperature remains stable at +20 °C, but the concentrations of the salt and the buffer solutions are varied from sample to sample, so investigators can determine which concentration promotes the growth of better, larger crystals.

The protein to be crystallized is bacteriorhodopsin, a well-known membrane protein that converts light energy to voltages in the membranes of photosynthetic archaebacteria (primitive microorganisms that are chemically and genetically distinct from bacteria and higher living organisms). Microbiologists are interested in this system because bacteriorhodopsin represents an almost ideal system in which to study light-energy-driven vectorial membrane transport that developed in Earth's early environment.

Many ground-based experiments have been done with bacteriorhodopsin, which forms two-dimensional crystals in high salt concentrations. However, resolution of the three-dimensional structure, which will help biologists understand how bacteriorhodopsin works, depends on the availability of isometrically large, highly-ordered crystals. Hitherto, high-quality crystals have not been grown under terrestrial conditions.

Crystallization of Proteins and Viruses in Microgravity by Liquid-Liquid Diffusion

Principal Investigator: Dr. Alexander McPherson

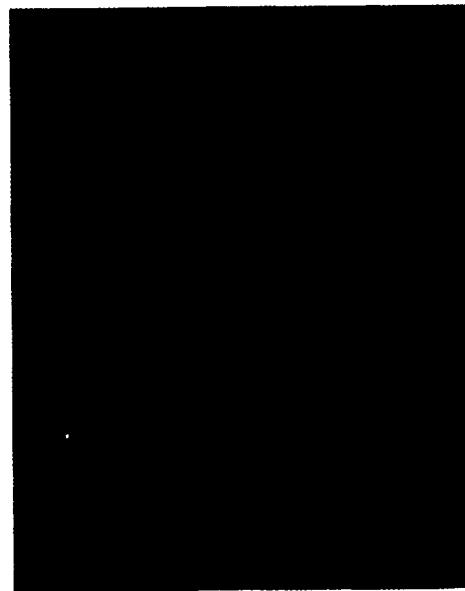
University of California at Riverside, Riverside, California, USA

In this investigation, two proteins and a virus will be crystallized. The proteins are canavalin (the major storage protein of leguminous plants and a major dietary protein) and catalase (an important detoxifying enzyme from the liver). The virus is satellite tobacco mosaic virus, a common plant pathogen and one of the smallest viruses in existence. Each of these macromolecules and the virus are the subjects of extensive biochemical and molecular biological interest.

Two duplicate samples of each protein and the virus are crystallized during the flight, with one of each pair using the Cryostat in the freezer mode where it experiences a temperature gradient over the course of the experiment of -4 to +20 °C. The alternate sample of each pair is crystallized under identical conditions but is maintained at a constant temperature of +20 °C by Cryostat in the stabilizer mode.

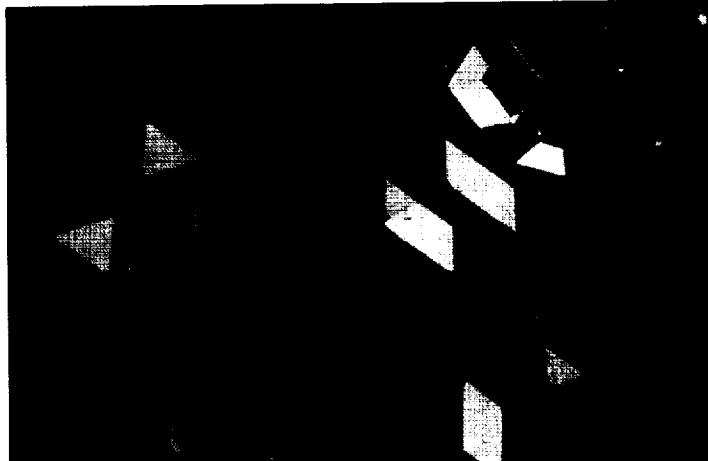
Both proteins and the virus can be crystallized in more than one form on Earth. An objective of this experiment, in addition to evaluating the potentially beneficial effects of a microgravity environment free of convection and sedimentation, is to investigate the effect of microgravity on crystal polymorph distribution and size under diverse conditions of temperature.

Canavalin and satellite tobacco mosaic virus were crystallized in microgravity on previous flights using the vapor diffusion method in the Protein Crystal Growth hardware, which is also flying on IML-1. A second objective of this experiment is to compare crystals obtained from the Cryostat using liquid diffusion techniques with those obtained using the Protein Crystal Growth vapor diffusion methods.



Bacteriorhodopsin crystals have been crystallized on the ground but are not good enough for scientists to define the crystal's three-dimensional structure.

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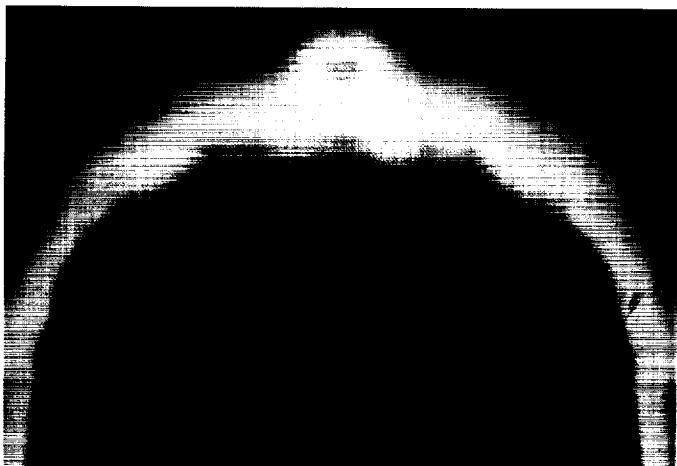


Canavalin crystals will be grown in the Cryostat by liquid diffusion. They will be compared with crystals grown in the Protein Crystal Growth experiment by vapor diffusion.

Fluids Experiment System

■ Provided by: NASA

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Spacelab 3 scientists used the black-and-white image (top) showing density profiles in the fluid surrounding a triglycine sulfate crystal to generate a color computer map (bottom) of fluid concentrations. The crystal was growing when the image was made; blue denotes the area near the crystal surface. IML-1 scientists want to learn more about how crystals grow from solution in microgravity.

Two investigations use the Fluids Experiment System, a facility that has sophisticated optical systems for imaging fluid flows during materials processing. The facility contains an enclosure for experiment processing inside an optical bench. The optics include a laser system for making holograms of samples and a video camera for recording images of fluid flows in and around samples.

Study of Solution Crystal Growth in Low-Gravity

Principal Investigator: Dr. Ravindra B. Lal

Alabama A&M University

Normal, Alabama, USA

Triglycine sulfate crystals are grown from solution using the Fluids Experiment System. Considerable ground-based work has been completed in growth and characterization of this crystal. The crystals have technological potential as infrared detectors that can be used at room temperature with small cooling devices. There are many applications for improved infrared detectors in military systems, astronomical telescopes, Earth observation cameras, and environmental analysis monitors. Unfortunately, when these crystals are grown to useful sizes on Earth, they develop defects that limit their performance.

To grow high-quality triglycine sulfate crystals, scientists use a seed: a slice from the face of a larger crystal of highest quality grown on Earth or a small crystal nucleated from solution in a ground-based laboratory. The seed is immersed in a solution of triglycine sulfate that has been heated slightly to remove any seed surface imperfections. As the seed is cooled at a programmed rate, the triglycine sulfate diffuses to the interface and incorporates around the seed to form layers of new growth. On Earth, gravity causes convective flows in the solution, which results in nonuniform growth and microscopic flaws that affect the crystal's electrical and optical performance. In space, where convection should be limited and diffusion is the dominant transport mechanism, it should be possible to produce more nearly perfect crystals.

Triglycine sulfate solution is transparent, so it is possible to record holographic images of fluid motion around a growing crystal. This way, scientists can monitor fluid motion to see the effect of reduced convective flows and determine how solution crystal growth takes place in space. Two types of images are made: schlieren images (transmitted during the mission as black-and-white video that reveals variations in fluid density and flow patterns) and holograms (three-dimensional recordings that can be reconstructed as images to show density variations near the sample). Holograms and video data are recorded during mechanical operations and critical phases of crystal growth. During the experiment, the principal investigator and his team monitor downlinked video of the crystal and the growth solution and may instruct the crew to adjust the temperature to induce more uniform crystal growth by changing the growth rate.

The first crystal is grown for a minimum of 1 day. During this run, investigators want to study the fluid flow in three dimensions. To achieve this, the triglycine sulfate solution is filled with small particles that can be imaged to show the direction and velocity of fluid movements caused by background accelerations created by mechanical devices and crew motion. Scientists use data from the first run to try

to grow a single, high-quality crystal during a second run that lasts several days. No tracer particles are present during this run because they would contaminate the crystal. Seed crystal orientation, fluid concentration, and growth temperature may be different for this run.

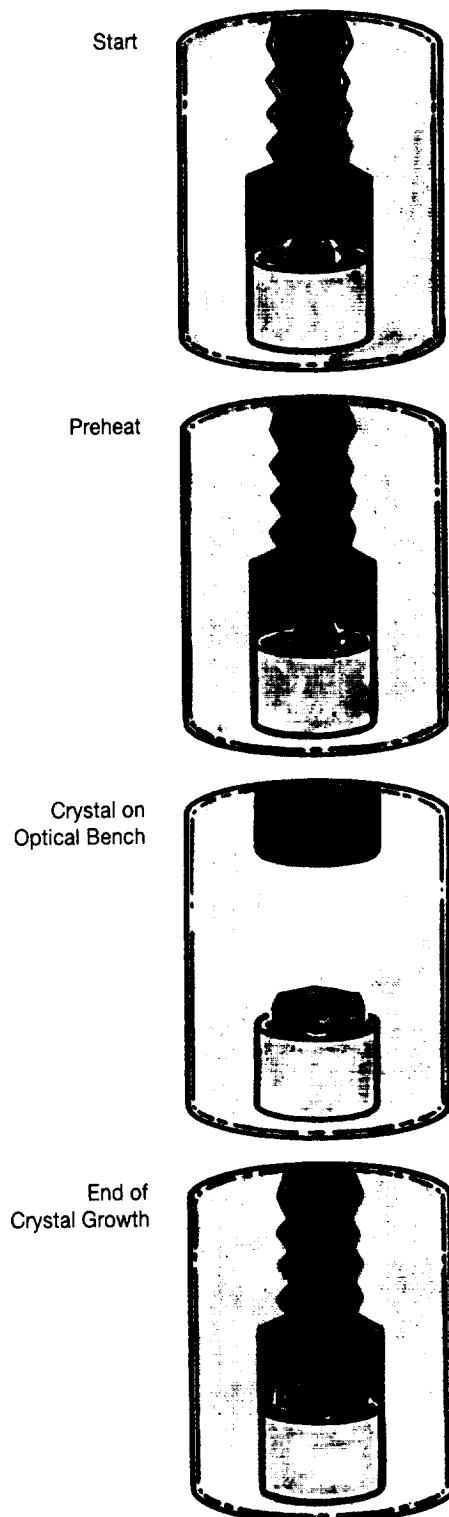
The crew begin each run by placing a sting (a temperature-controlled rod) with an attached seed crystal in a test cell filled with about 1 l (0.26 gal) of triglycine sulfate in a water solution. Each cylindrical seed crystal is 1 to 1.5 cm (about 0.4 to 0.6 in.) at the base. The seed and fluid are separated by a cap assembly that is retracted when the experiment begins.

To dissolve all small crystallites that will have formed in the solution at room temperature, the test cell is preheated while the sting is kept at a cooler temperature so as not to dissolve the seed. Next, the cell is cooled while the sting is heated to bring the sting and the fluid to the proper temperature so that part of the seed is dissolved to remove any surface imperfections after the cap over the crystal is retracted. The test cell and solution, sting, and optical bench are then cooled further, which causes triglycine sulfate to come out of the solution and deposit on the surface of the seed. A slow but uniform growth of about 1 mm (0.04 in.) per day is expected. At the end of the run, the cap is closed, the crystal is cooled, and the test cell is removed from the optical bench. The sting is removed from the test cell and stored in a specially designed container that allows the crystal to cool slowly to room temperature.

After the mission, the crystals are returned to the investigator for extensive analysis of their structures and properties, including their capability of infrared radiation detection. The crystals grown in space are compared with crystals grown by the same technique on the ground and with commercial triglycine sulfate crystals.

Two triglycine sulfate crystals grown in the Fluids Experiment System during the Spacelab 3 mission shed light on how defects are formed and what role convection plays in creating defects, something that is not well understood. In the space-grown crystals, the boundary (interface) between the seed crystal and the layer grown in space could not be seen using optical microscopy. In Earth-grown crystals, defects called inclusions are typically formed at this boundary, with more defects called dislocations emerging from the inclusions into material grown on top of them. In space, the transition from dissolution to growth occurs slowly under diffusion-controlled conditions and without convection, which could result in fewer defects. The Spacelab 3 crystals were smaller than expected, but excellent holograms clarified what happened: differences in fluid concentrations around the seed crystal's edge caused a concave surface to form, resulting in uneven crystal growth.

On IML-1, accelerations that cause convection and disturb crystal growth are carefully monitored. The Space Acceleration Measurement System has two accelerometers located in the Fluids Experiment System rack and one more mounted in the Spacelab center aisle. This special set of accelerometers measures low-frequency (0 to 5 Hertz) vibrations that occur on Spacelab and are called g-jitter. The triglycine sulfate crystal experiment is very sensitive to g-jitter because it can cause convective flows in the growth solution. Any flows resulting from g-jitter can also be monitored with the crystal growth facility's optics.



Crystal growth process in the Fluids Experiment System

**An Optical Study of Grain Formation:
Casting and Solidification Technology (CAST)**
Principal Investigator: Dr. Mary H. McCay
University of Tennessee Space Institute
Tullahoma, Tennessee, USA



Freckles in a metal alloy cause imperfections to the structure.



IML-1 crew members practice using the CAST hardware.

Advanced alloys, which are made by combining two or more metals or a metal and a nonmetal, are essential for such products as jet engines, nuclear power plant turbines, and future spacecraft. Many of the advantageous properties of metal alloys such as mechanical strength and corrosion resistance may be altered and improved by processing them in space. This experiment solidifies a salt (ammonium chloride) and water solution that models the freezing of alloys. The salt is transparent, which makes it ideal for optical observations of fluid flow and crystallization. Metallurgists use material such as this to study the way grains form in alloys, undercooling effects on metal structure, and the interface between the liquid and solid parts of a solidifying sample.

As an alloy solidifies, dendrites form tree-shaped crystals similar to snowflakes. These dendrites play an important role in determining the microstructure of alloys. If undesirable dendrites form, a processed alloy may have an imperfect grain structure.

Current experiment data have not revealed why spurious dendrites form, but fluid motion or constitutional undercooling (when the combination of temperature and composition causes the alloy to freeze at a lower than normal temperature) may be the cause. An example of a solid forming in an undercooled liquid is an ice crystal (solid) growing inside a glass of pure water (liquid) that is cooled below its freezing point. The rate at which the ice freezes is controlled almost entirely by the rate at which the latent heat generated at the solidification front between the ice and water can diffuse away through the liquid. On Earth, the freezing of undercooled liquids is hard to study because of gravity effects, such as convection, which alter the temperature across the sample. In weightlessness, density variations should not cause convective flow, so investigations can isolate the constitutional undercooling effect to see if it causes undesirable crystallites to form.

Dendrite coarsening, the formation of crystal branches or arms, is the small-scale phenomenon primarily responsible for the final grain structures of an alloy. If the grains are not uniform, the alloy may not be as strong. Sometimes smaller dendrite arms dissolve and shrink and larger arms grow. Experiments have shown that the spacing of dendrite arms varies with gravity level, indicating that gravity subtly affects the concentration of fluid immediately adjacent to an arm and, thus, affects the final metal structure.

Also of particular interest is the interface or growth front between the solid and liquid parts of a solidifying alloy. The formation of the front is influenced by the temperature gradient, growth rate, and fluid motion. In some commercial materials such as stainless steels and superalloys, a phenomenon known as freckling occurs and tends to limit the usefulness of alloy compositions. Freckles are small grains caused by upward-flowing liquid plumes. These plumes occur at the growth front within the mushy zone that is just beginning to freeze. They contain cooler liquid with a different composition than the surrounding region, and they move through the forest of dendrites, carrying crystal fragments that appear as trails of small grains in the final alloy. The freckles have a different composition, melting point, and structure than the rest of the alloy, causing imperfections. These freckling plumes should be easily seen using the Fluids Experiment

System optical techniques. The formation of liquid plumes and concentration gradients across the plumes and in the diffusion layer ahead of the interface should be visible; the driving force for the formation of the plumes can then be identified.

To study these solidification processes, three experiment samples of ammonium chloride and water are used. They are flown in rectangular-shaped containers, called cuvettes, made of optical-quality quartz to allow fluid and dendrite growth processes to be observed. The cuvettes fit inside a larger module that is installed in the Fluids Experiment System experiment enclosure.

Two of the samples are filled with a solution consisting of water and 28 percent salt by weight, and the third is filled with water and 15 percent salt by weight. A series of up to 11 experiments may be run, using the samples repetitively. For most of these runs, samples are solidified under the controlled conditions of directional solidification, and for the other runs, samples are undercooled prior to rapid solidification. The duration of each run is determined by the growth rate and ranges from 30 minutes to 2 hours.

To begin each run, a cuvette module is attached to a premelt controller, and one end of the cuvette is raised to a temperature hot enough to completely liquify the sample. The sample is maintained at the temperature required to keep the salt in solution, and it is moved

to the experiment enclosure for the main portion of the experiment. Here, it is solidified under three temperature gradients, providing a series of varying growth rates. Temperature and, therefore, growth rates and temperature gradients are controlled by thermoelectric coolers attached to the ends of the cuvette. When the temperature gradient is established and the sample is quiescent, the crew member adjusts the temperature profile to induce directional solidification from one end of the sample to the other. For the undercooling runs, maximum cooling is applied to the cold end, causing the sample to solidify rapidly. With the series of runs, solidification can be studied first under optimum conditions and then under conditions that enhance freckling and crystallite formation ahead of the growth front where liquid and solid meet.

Holograms are taken during each growth run. Postflight, they can be reconstructed to show dendrite formation and the growing interface. Using other optical techniques, the temperature and concentration profiles can also be obtained. Three temperature sensors around the cuvettes record data that are correlated with calculations. During the critical period when the solidification front moves through the cuvette, video is downlinked to investigators on the ground who can confer with a crew member and request that changes be made to the experiment during present or future runs.



A member of the CAST investigator team tests an optical system similar to the one that will record data as samples solidify in space.

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Vapor Crystal Growth System

■ Provided by: NASA

Vapor Crystal Growth Studies of Single Mercury Iodide Crystals

Principal Investigator: Dr. Lodewijk van den Berg
EG&G, Inc., Goleta, California, USA

The ability to control the growth of a large mercury iodide crystal in microgravity was demonstrated with the Vapor Crystal Growth System flown on Spacelab 3 in 1985. A crystal grown for 100 hours was comparable to the best crystals grown on the ground. The crystal quality, analyzed by reflecting X-rays, was better than the ground-based crystal used as a standard, and gamma-ray tests showed the interior quality to be better than mercury iodide crystals grown on Earth.

Two important lessons were learned during the mission: the crystal could be grown faster than expected, and the interaction between the onboard payload specialist and the scientists on the ground was essential for growing the best crystal possible. The payload specialist on Spacelab 3, who is the principal investigator for this IML-1 experiment, was able to recognize that the crystal was growing too slowly. After consulting with investigators in the ground control center who were observing the crystal's growth on video transmitted from the spacecraft, the payload specialist increased the temperature to initiate faster crystal growth.

On IML-1, this interaction between the crew and investigators continues. Images are relayed to the ground via television, and payload specialists view the crystal through a microscope imaging system. This allows the process to be tracked through each stage, and scientists can change parameters (such as temperature) to adjust growth and reduce defects, much as they do in ground-based laboratories.

Based on the Spacelab 3 results, investigators have decided to grow the IML-1 crystal twice as fast. This accelerated growth is possible because in the absence of gravity-driven convection, the vapor is

Mercury Iodide

Mercury iodide crystals have practical uses as sensitive X-ray and gamma-ray detectors. In addition to their exceptional electronic properties, these crystals can operate at room temperature rather than at the extremely low temperatures usually required by other materials. Because a bulky cooling system is unnecessary, these crystals could be useful in portable detector devices for nuclear power plant monitoring, natural resource prospecting, biomedical applications in diagnosis and therapy, and astronomical observing.

Although mercury iodide has greater potential than existing detectors, its performance has not met expectations. Problems in the growth process cause crystal defects, and unstable convective flow may cause the crystal to grow unevenly. Furthermore, this crystal is fragile and can be deformed by its own weight. Scientists believe that the growth process can be controlled better in microgravity where large, single crystals with few defects can be processed.

Mercury iodide crystals grown as source material are heated, vaporized, and then condensed on a seed crystal. When gravity-related convection is minimized, variations in the mercury iodide vapor being deposited on the seed crystal will be reduced. Movement of the vapor will then occur mainly by diffusion as the source evaporates and uniformly condenses on the seed to form new growth. In weightlessness, strain deformities caused by the crystal's weight will be reduced considerably.

Two complementary facilities, the Vapor Crystal Growth System and the Mercury Iodide Crystal Growth facility, produce mercury iodide crystals. While both investigations use vapor transport to form crystals, parameters such as temperature and pressure are varied to determine the optimum conditions for producing these crystals. Both facilities have been flown on previous Spacelab missions and have successfully grown crystals. IML-1 gives investigators the opportunity to refine their techniques and continue to study this process through iterative research.

deposited around the seed more uniformly. On Spacelab 3, the growth conditions were changed slowly because investigators were not sure what conditions would be ideal in space. This time the faster speeds that were effective at the end of the Spacelab 3 experiment are used during the entire growth process on IML-1. The same hardware has been modified slightly and is being reflown.

Before the mission, the principal investigator repeatedly grows a tiny seed crystal on the temperature-controlled pedestal inside the ampoule. Then, he selects the best quality seed for the mission. The mercury iodide source material is mounted to the inner wall of the ampoule. The ampoule is put in a heater assembly and installed in the furnace enclosure, a bell-jar-shaped container.

In space, a crew member inspects the seed crystal and installs the bell jar in the experiment enclosure in the Vapor Crystal Growth System. Heaters are started, and the ampoule is warmed to temperatures of around 100 °C. At this point, the ideal growth temperature is established, and the mercury iodide source evaporates and condenses on the seed, which is maintained at a temperature around 40 °C. The vapor molecules follow the structure of the seed to produce a larger crystal. Growth continues for approximately 100 hours, with crew members and investigators monitoring and changing temperatures as necessary to enhance growth. At the end of the experiment, the ampoule is cooled, and the module is removed and stowed.

Postflight, the crystal is returned to the principal investigator who will compare it to the Spacelab 3 crystal and ground-based crystals, examine its structure using standard X-ray and gamma-ray analyses, and test its high-energy radiation detection properties. From a seed crystal about 3 mm (0.12 in.) on a side, scientists should be able to produce a crystal up to 12 mm (0.48 in.) on a side, slightly larger than a sugar cube. If ideal growth conditions can be determined through Spacelab experiments, investigators want to grow these crystals longer in facilities inside permanent spacecraft like Space Station Freedom. On the ground, these crystals are grown for more than 3 months and reach sizes as big as baseballs.

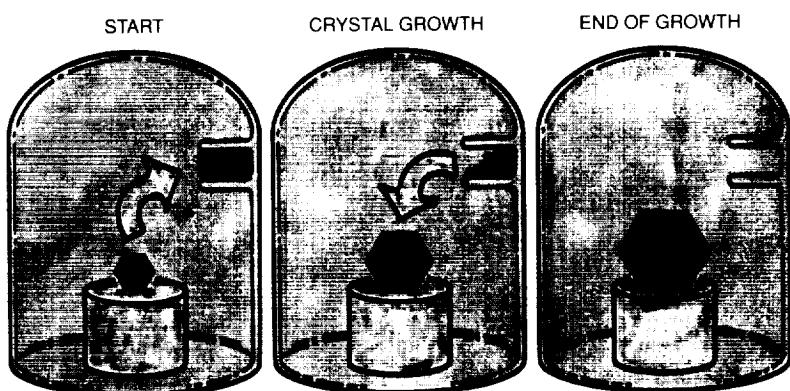
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The IML-1 Vapor Crystal Growth System principal investigator was a payload specialist for the Spacelab 3 mission and grew a very high-quality mercury iodide crystal.



This mercury iodide crystal was grown in the Vapor Crystal Growth System during the Spacelab 3 mission. For IML-1, scientists are growing the crystal at faster rates, which should result in a larger crystal of the same high quality as the one previously grown in space.



Seed temperature slightly warmer than source; mercuric iodide moves from seed to source to etch surface of seed.

Seed cooled to begin growth of crystal; mercuric iodide atoms move from source to seed.

No source material is present; final crystal size is 1 cubic centimeter.

Crystal growth process in the Vapor Crystal Growth System

M ercury I odide C rystal G rowth

■ Provided by: CNES

**Mercury Iodide Nucleations and
Crystal Growth in Vapor Phase**
Principal Investigator: Dr. Robert Cadoret
University of Clermont-Ferrand
Aubière, France

The Mercury Iodide Crystal Growth experiment was flown on Spacelab 1 in 1983 and Spacelab 3 in 1985. On Spacelab 1, a simple furnace heated a mercury iodide source and caused it to evaporate and condense in a cooler part of the container to form small crystals. The experiment was repeated on Spacelab 3, but this time temperatures were varied, and the source was exposed to different pressure conditions. The IML-1 investigation uses six single-seed crystals obtained from mature crystals grown on the ground. They are placed in separate containers to grow large crystals under controlled conditions.

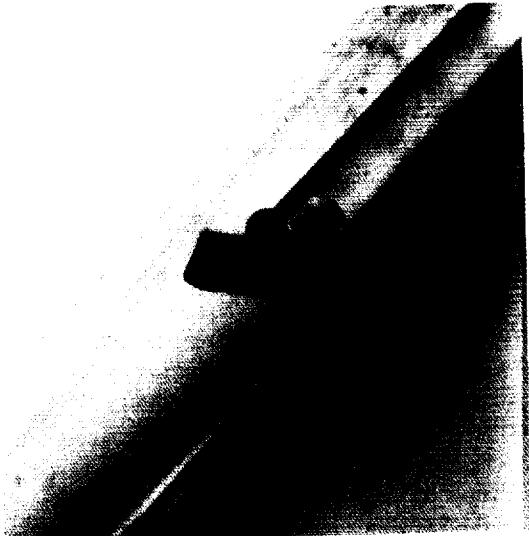
The furnace holds three samples, each inside a clear ampoule surrounded by stainless-steel cartridges, with the heating element located between the ampoule and the steel container. At the beginning of the experiment, a crew member inspects the ampoules, places them in the facility, and turns it on. Periodic checks are made of furnace temperature, and adjustments are made at the request of the investigator.

Three temperature zones exist between the hot end (source) and the cold end (sink) of each ampoule. The payload scientist increases the temperature at the mercury iodide source in 1-°C increments from 107.5 to 111.5 °C. As the source is heated, it evaporates and moves through the cartridge. Some source material is distributed symmetrically around a 2-mm (0.08-in.) seed in the center of the ampoule; the seed is mounted on a small pedestal kept slightly cooler. Additional source matter is deposited in the cold sink so that it does not condense and form small crystallites near the seed crystal.

On Earth, gravity-driven convection causes an uneven concentration of mercury iodide on the seed crystal because material settles only on certain parts of the seed. There are usually defects at the interface between the seed and new growth. In space, investigators hope to produce larger, nearly flawless crystals.

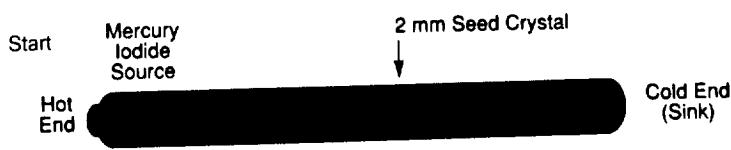
Investigators cannot observe crystal growth, but they can adjust the temperatures and make precise measurements of total pressure and the concentration distribution of mercury iodide inside the ampoules. A gas (nitrogen) in each ampoule creates different pressure environments from 0.5 to 1 Torr. This helps scientists determine the ideal pressure for growing crystals and aids in discerning how thermal diffusion affects mercury iodide distribution in each ampoule. This information complements the visual data obtained for the Vapor Crystal Growth System experiment.

After the first three crystals grow for an extended time, they are cooled for 4 hours and removed by the payload specialist. The growth process may be repeated with three more crystals, if time is available. Then, the furnace is turned off, and the samples are removed and stowed. Postflight, the crystals are returned to the investigator who will analyze their structures and determine which pressure environment provides the best growth conditions.



ORIGINAL PAGE
COLOR PHOTOGRAPH

*This crystal was grown on the ground inside the
Mercury Iodide Crystal Growth furnace.*



Temperature at source increased in 1 °C increments
from 107.5 to 11.5 °C. Seed kept cool at 102.5 °C.



Hot source material vaporizes and then
condenses on seed. Some source material
is deposited in sink kept at 85 °C.

All source material is deposited on
crystal or in sink.

*Crystals are grown in individual ampoules in the
Mercury Iodide Crystal Growth furnace.*

Organic Crystal Growth Facility

- Provided by: NASDA
- Principal Investigator: Dr. A. Kanbayashi
National Space Development Agency of Japan
Tokyo, Japan

Organic substances contain a variety of compounds with physically interesting properties that can be useful for various applications. The Organic Crystal Growth Facility is used to grow superconductors, metals or alloys that conduct electric current with no resistance. Although these materials may have impurities, they stop scattering electrons and conduct electricity very efficiently. Superconductors are key components of computers, communications satellites, and many other electrical devices.

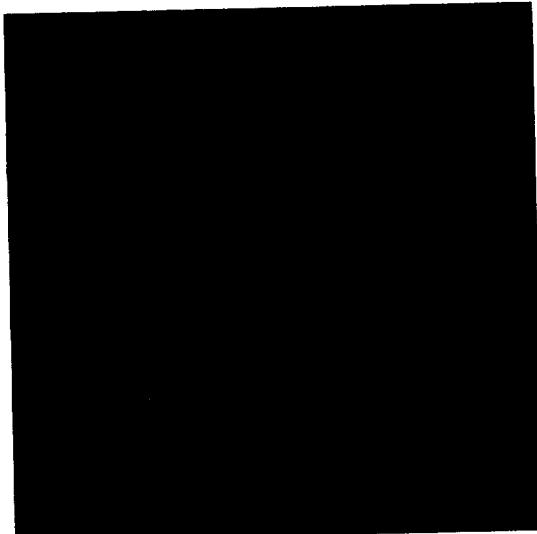
A group of organo-metallic conducting compounds composed of charge transfer complexes are of special interest to scientists. For IML-1, an organic crystal composed of two charge transfer complexes, tetrathiafulvalene (TTF) and $\{\text{Nickel}(\text{dmit})_2\}_2$, is grown from solution. [Dmit stands for (4,5 dimercapto-1,3 dithiol-2 thionel).] Researchers are interested in this crystal because it is organic — containing a hydrocarbon found naturally in living organisms — but it acts like a metal superconductor and transfers charge. Organic-metal conductors including organic superconductors have unique conducting properties that depend largely on their singular crystal structures.

To study the metallic conduction properties in detail, it is necessary to grow large, high-quality, single crystals of charge transfer complexes that may exhibit low-dimensional metallic conduction. However, it has been very difficult to grow organic single crystals on Earth because sedimentation and thermal convection disturb growth. To date, very small needle-like crystal fragments were grown on the ground, but they were not large enough to determine the crystal's superconducting properties. IML-1 investigators want to grow a single crystal large enough to analyze its intrinsic physical properties — a crystal more than 10 times larger than ground-based ones.

The Organic Crystal Growth Facility has two growth chambers: a large chamber for growing a big crystal and a small chamber with a window for observing the growth of a smaller crystal. A crew member starts the experiment on the first day, and it runs automatically, growing two crystals simultaneously for the length of the mission. Periodically, the crew member uses a 35-mm camera to photograph crystal growth in the small chamber. Temperature and vibration data are automatically recorded for both chambers.

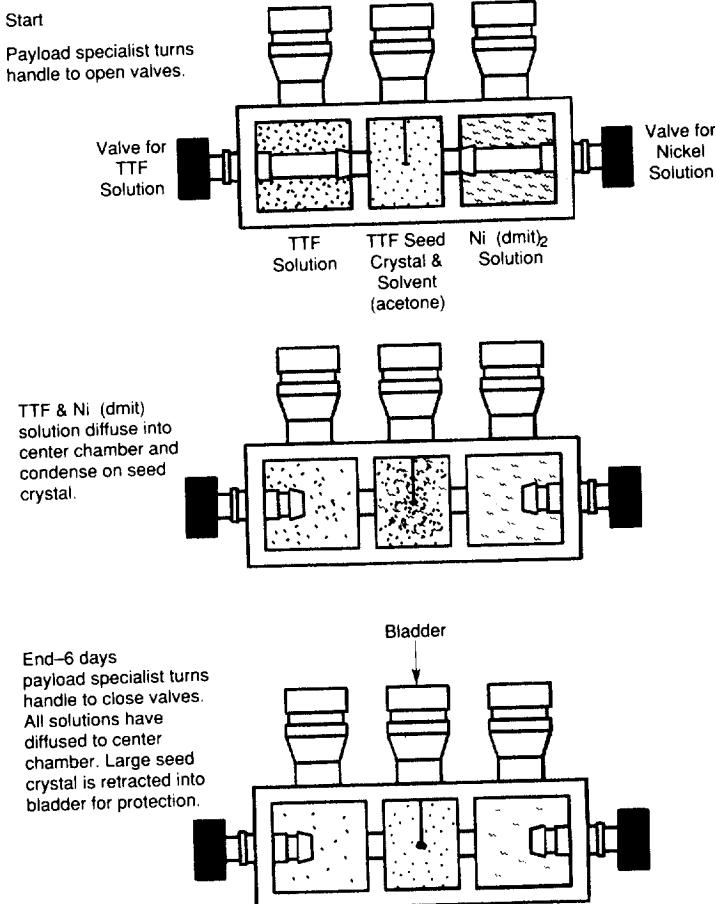
A seed crystal is mounted on a gold wire in the center section of each chamber; this chamber also contains acetone, which acts as a solvent. A chamber on one side is filled with the accepter solution (a nickel solute) and the chamber on the other side is filled with the donor solution (TTF solute). The payload specialist cranks a handle that lowers the seed crystal into the center of the chamber. Two valves are opened in each side chamber allowing accepter and donor solutions to diffuse into the center chamber and condense on the seed. This reaction of organic crystal growth requires 6 days to complete. At the end of the experiment, a crew member cranks a handle that closes the two valves and raises the crystal into a protective bladder to prevent further growth under 1-g conditions postflight. After the mission, the bladders are given to the principal investigator who removes the crystals and analyzes their structures, perfection, electrical and magnetic properties, superconductivity, and other important parameters.

A second goal of the experiment is to monitor g-jitter accelerations that mimic gravity and cause convection and other disturbances. The mounting beam that holds one of the growth chambers is made of damping material (an epoxy-based polymer) and aluminum, whereas the mounting beam of the other chamber is made of aluminum only. Accelerometers mounted on each chamber measure the amplitude and frequency of the accelerations, so that scientists can determine if the jitter is absorbed by the epoxy-aluminum beam.



These superconducting crystals about 1 mm in size were grown on the ground inside the Organic Crystal Growth Facility. IML-1 scientists hope to grow crystals that are 10 times larger.

ORIGINAL PAGE
COLCR PHOTOGRAPH



Crystal growth process in the Organic Crystal Growth Facility

Critical Point Facility

■ Provided by: ESA

All materials exist in different states that depend on pressure and temperature. For example, at atmospheric pressure on Earth and temperatures less than 100 °C, water exists as a liquid. When we raise the temperature above 100 °C, the water goes through a phase transition and becomes a vapor: steam. During this phase transition, the density of water also changes; steam of the same mass as liquid water has a volume 1,600 times greater than the liquid. Since the vapor occupies a much larger volume, it is not nearly as dense as the liquid, which occupies less space.

The boiling temperature of all fluids depends on the pressure. If you increase the pressure, the fluid will boil at a higher temperature and be more dense when it changes to vapor. The differences between liquid and vapor density decrease as pressure and temperature increase until — at the critical point — there is no difference in the density of the fluid in the liquid and vapor states. At the critical temperature and pressure, regions of the fluid fluctuate rapidly between liquid and vapor in a wavelike manner.

Scientists are interested in what happens to materials at their critical points because critical point phenomena are universally common to many different materials. Physically different systems act very similarly near their critical points. Thus, the behavior of matter at a critical point can be related to many disparate physics problems from liquid-vapor and compositional phase changes in fluids to compositional and magnetic phase changes in solids.

In the late 1960s and early 1970s, scientists studied critical phenomena using new experimental techniques based on lasers and new theoretical approaches. They demonstrated that even processes as complex as critical point phenomena have an underlying mathematical order. Unfortunately, fluid experiments that verify these theories are difficult to perform because gravity distorts the density of samples, limiting the acquisition of data. The availability of low-gravity conditions on longer duration space missions has resurrected these investigations. In fact, a recent international workshop sponsored by NASA and the National Institute of Standards and Technology concluded that unexpected behavior of fluids near the critical point in low-gravity opens up equilibration dynamics as a new frontier in critical phenomena research.

Fluid compressibility near the critical point is the root of the troubles caused by gravity. The fluid's compressibility is high, and only a small force is required to compress the sample. Theoretically, at the critical point, compressibility becomes infinite.

Scientists study critical phenomena by attempting to maintain a sample of constant volume so that the average density of the sample is equal to the critical density. However, on Earth, a large portion of the sample cannot be maintained at the critical point because the fluid's own weight is sufficient to compress half of the sample to a density greater than the critical density, while the remaining half of the sample has a density less than that of the critical density. Only a thin portion of the sample between the two halves of the sample is at the critical density. As the sample nears the critical temperature, the fluid becomes more compressible, and the critical zone becomes smaller. At some temperature, the zone becomes too small to allow scientists to use known laboratory measurement tools to probe fluid thermodynamic properties. In space, microgravity reduces the weight of the fluid on itself and widens its critical zone. Best of all, it allows scientists to make measurements closer to the critical temperature before reaching the limits of instrumentation.

Another interesting physical phenomenon is the time it takes for an entire sample to reach the same temperature (thermal equilibrium) as it approaches the critical point. That time approaches infinity as the sample nears the critical point. The uncertainty in these time scales has spawned scientific interest, and long-duration space experiments will be required to measure them.

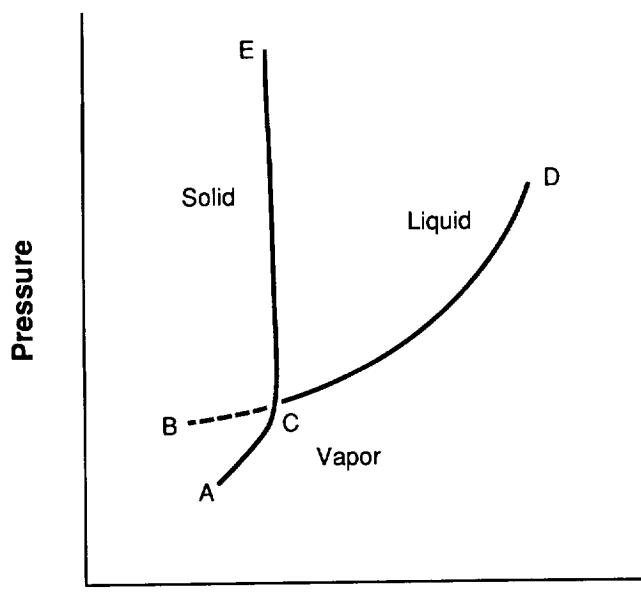
The Critical Point Facility comprises two interconnected drawers: an electronics drawer and an experiment drawer. The electronics drawer contains the power supply and electronics and data handling systems. The experiment drawer contains a thermostat; it encloses a test cell that houses the fluid being tested, mechanical and acoustic stirrers, and diagnostic devices for thermal and optical analysis of the sample. For each experiment, a 1- to 5-cm³ (0.64- to 3.2-in.³) test cell will be filled to the critical density and have a pressure of tens of atmospheres.

Temperature is the only variable that will change. The thermostat is a technological feat, capable of heating or cooling fluids at increments of 1 milli-degree C for temperatures ranging from 30 to 70 °C. The test cell for the fluid is a small portion of the thermostat and has ports for optical observations and stirrers to mix fluids. The acoustic stirrer uses sound waves at 1.7 Megahertz to mix incompressible fluids for short periods and eliminate any density or concentration inhomogeneities in the sample. The mechanical stirrer is better suited for compressible fluids.

A collimated red laser beam focused through an optical port in the thermostat is refracted by the fluid, producing interference patterns

that are recorded by video and still cameras mounted on the outside of the thermostat. These patterns will reveal the density profile of the fluid, which is affected by temperature changes and small Shuttle accelerations. Another green light source is transmitted through the sample to backlight it so that fluid behavior, such as fluid motion or conditions at the liquid-vapor interface, can be visualized. A second laser beam passes through the sample and is scattered by the density or concentration fluctuations of the fluid near the critical point. The scattered light is detected at a variety of angles with respect to the incident laser beam and provides a means of sizing the density or concentration domains. Some of the light from the second laser beam does not get scattered; it is measured to determine the sample's turbidity. All fluids become milky as they near the critical point.

Four different experiments are planned inside the Critical Point Facility, which is primarily for optical studies of transparent fluids. The facility's electronic system runs each experiment automatically according to predetermined scenarios defined by each principal investigator. Since there is no natural convection in microgravity, thermal equilibration is much slower than on Earth; hence, temperature parameters are changed slowly, with experiment durations ranging from 15 to 60 hours. Crew members set up the experiments, start them, report on samples at their critical points, exchange thermostats and film, and shut down the facility. Video images and thermal data are transmitted directly to the investigators for analysis. Both the investigator and the payload specialist can modify preprogrammed experiment parameters to change an experiment in progress.



Schematic phase diagram for a one-component system, such as water. C is the triple point where ice, water, and water vapor coexist. D is the critical point, where a kilogram of water and a kilogram of water vapor have the same volume and the distinction between the two phases vanishes. BC, which is an extension of the vapor pressure curve CD, is the curve of the supercooled liquid. AC is the sublimation curve of the solid (corresponding to the evaporation of ice), and CE is the melting curve.





Study of Density Distribution in a Near-Critical Simple Fluid

Principal Investigator: Dr. Antonius C. Michels
Van der Waals Laboratory
Amsterdam, The Netherlands

This 60-hour experiment uses visual observation, interferometry, and light scattering techniques to examine and analyze the density distribution in sulfur hexafluoride (SF_6) above and below the critical temperature. The fluid SF_6 is used because its critical temperature is near room temperature, and therefore large amounts of power are not needed to heat or cool the fluid.

Below the critical temperature, the fluid exists in liquid and vapor phases. The spatial separation of these phases on Earth — vapor above and liquid below — is not an intrinsic property of the fluid system but is caused by gravity. At a fixed temperature and pressure, the density of each of the coexisting phases is fixed. However, near the critical temperature, gravity-induced hydrostatic forces will result in a gradual decrease in density with increasing height in the sample container. Thus, gravity determines the density distribution of the critical sample, and if the temperature is changed, gravity also affects the way the sample equilibrates to reach one density.

This experiment studies the density distributions of samples and how they equilibrate. It will also analyze the influence of forces weaker than gravity, such as the adhesive surface forces near container walls, and examine the interface between coexisting phases. Interferometer patterns will be used to determine local density and thickness of surface interface layers. Light scattering data will reveal the size of density fluctuations on a microscopic scale. Visual observations will verify the sample's behavior.

Heat and Mass Transport in a Pure Fluid in the Vicinity of a Critical Point

Principal Investigator: Dr. Daniel Beysens
C.E.N.
Saclay, France

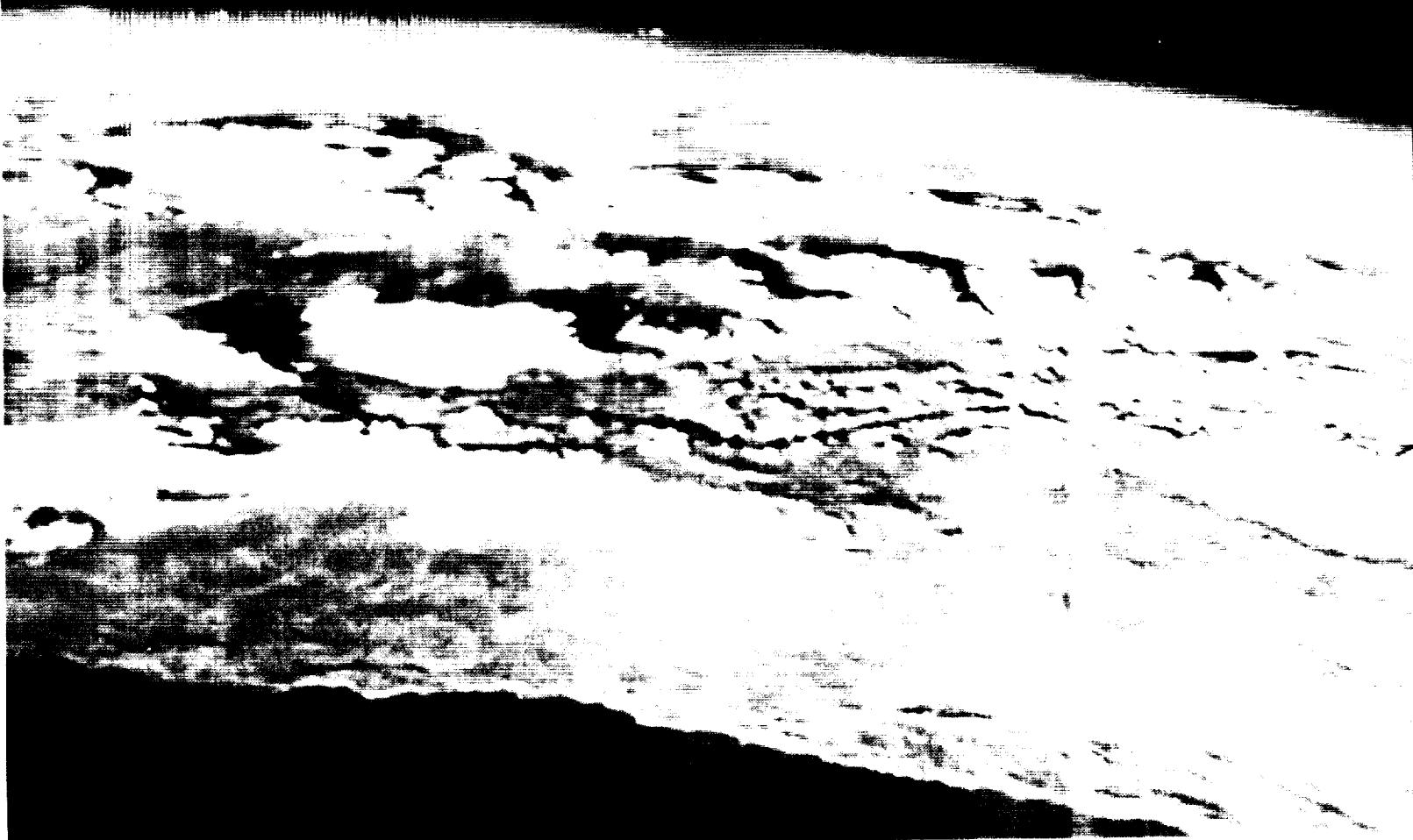
On Earth, gravity-induced convection speeds up heat and mass transport inside a fluid sample. In a gas-liquid system near the critical point, the system is very unstable on Earth, even when it experiences very small temperature changes. Thus, heat and mass transport on a large scale are performed through gravitational instabilities. In microgravity, three factors could influence the transport process: diffusion, convection caused by spacecraft accelerations, and container wall effects caused by a combination of the high compressibility of the fluid and the slow diffusion of heat.

This experiment uses interferometry and direct observation to study heat and mass transport in sulfur hexafluoride (SF_6), a gas of technological interest that can be obtained in a very pure form. The experiment examines heat and mass transport when temperature is increased from the two-phase region to the one-phase region; when it is varied in the one-phase region; and when it is lowered from the one-phase region to the two-phase region. Experiment results will be compared with results from ground-based runs to see if heat and mass transport is more efficient in orbit.





*On a past Shuttle mission, the IMAX camera
was used to take this picture of Earth.*





Phase Separation of an Off-Critical Binary Mixture

Principal Investigator: Dr. Daniel Beysens

C.E.N.

Saclay, France

Earlier microgravity studies with experiments on rockets have shown that for critical samples with the equilibrium phases of the same volume fraction, the influence of gravity on phase separation can be almost entirely suppressed. On Earth, this is accomplished by using carefully density-matched mixtures when the same volume fraction of the two liquid phases remains equal. Thus, the weak remaining gravity flows that drive the denser phase to the bottom of the container and the lighter one to the top are negligible. When the two phases are not equal in volume, e.g., when the concentration of the mixture is even slightly off-critical, the situation is not so clear because the growth becomes extremely slow. Therefore, gravity effects should be much more pronounced in an off-critical sample, making it impossible to separate phases on Earth as they would be separated in microgravity.

This experiment will study phase separation in off-critical systems. Investigators will examine how a fluid at the critical point separates from a single phase to form two phases. They are interested in how changes in temperature affect formation of the two phases. Phase separation at various temperatures will be studied using small-angle light scattering and direct observation. By comparing flight data to Earth-bound experiments, investigators can decide if microgravity-like conditions can be reproduced on Earth.

Investigation of the Thermal Equilibration Dynamics of SF₆ Near the Liquid-Vapor Critical Point

Principal Investigator: Dr. Allen Wilkinson

NASA Lewis Research Center

Cleveland, Ohio, USA

This experiment will examine the thermal relaxation and the fluid density profile as a function of time after a temperature perturbation is imposed on sulfur hexafluoride (SF₆) near its liquid-vapor critical point in the low-gravity environment of the Shuttle. Past low-g critical fluid experiments on Spacelab D1 yielded unexpected results that may have been caused by incorrect time scales for relaxation dynamics. Future experiments will depend on achieving thermal equilibrium within a specific temperature range and on knowing how the different phases develop or disappear. This work is intended to determine the practical time scale needed to execute meaningful critical fluid space experiments and characterize the location and dynamics of density or phase domains within the critical sample.

The 60-hour experiment timeline allows

- observation of homogenization as large phases of liquid and gas mix together with and without mechanical stirring (performed right after thermostat installation in the facility);
- interferometric observation of the evolution of heat and mass over time after the temperature of a one-phase system is increased or decreased;
- visual observation of the phase evolution and its configuration upon going to two-phase from a one-phase equilibrium;
- effects of stirring on a low-g two-phase configuration;
- two-phase to one-phase healing dynamics starting from a two-phase low-g configuration.

Two critical fluid thermal equilibration test cells are being developed to fit into one Critical Point Facility thermostat.

ML-1 Movie in Space

In addition to conducting science investigations, the IML-1 crew is filming scenes for a movie so that audiences on Earth can share their unique adventure. They use a camera system called the IMAX®, which has been used on previous Shuttle missions to produce exceptional images.

The IMAX camera and projector use a film frame 10 times the size of a conventional 35-mm frame and 3 times the size of a 70-mm frame. Since the IMAX film frame is so large, the IMAX screen can be 10 times the area of a conventional movie screen — up to seven stories high. IMAX films are presented in specially constructed theaters with seats on a sharp incline so that each viewer is close to the screen. The combined effects of the large screen, high-quality image, and seating configuration give the audience a vivid sense of "being there."

On the IML-1 mission, the IMAX camera is used to film footage for a motion picture commemorating International Space Year in 1992. The movie will chronicle the activities of the space-faring nations of the world in the exploration of our solar system and the Universe beyond. In addition to footage from the IML-1 mission, the film will include sequences on the preparation and deployment of the Hubble Space Telescope, the European Space Agency's launch of the Hipparcos satellite, and other recent advances in space exploration technology.

Since 14 countries are participating in IML-1, the mission illustrates the movie's theme of international cooperation in space. The makers of this film are also interested in the IML-1 experiments that study the effects of microgravity on humans, because the knowledge gained from this research will be essential to long-term space travel. Most of the footage is shot inside Spacelab so that audiences can see what it is like to work in a space laboratory.

This project is a result of a partnership between NASA, the National Air and Space Museum of the Smithsonian Institution, IMAX Space Technology, Inc., and Lockheed Corporation.

Epilogue: A Look to The Future

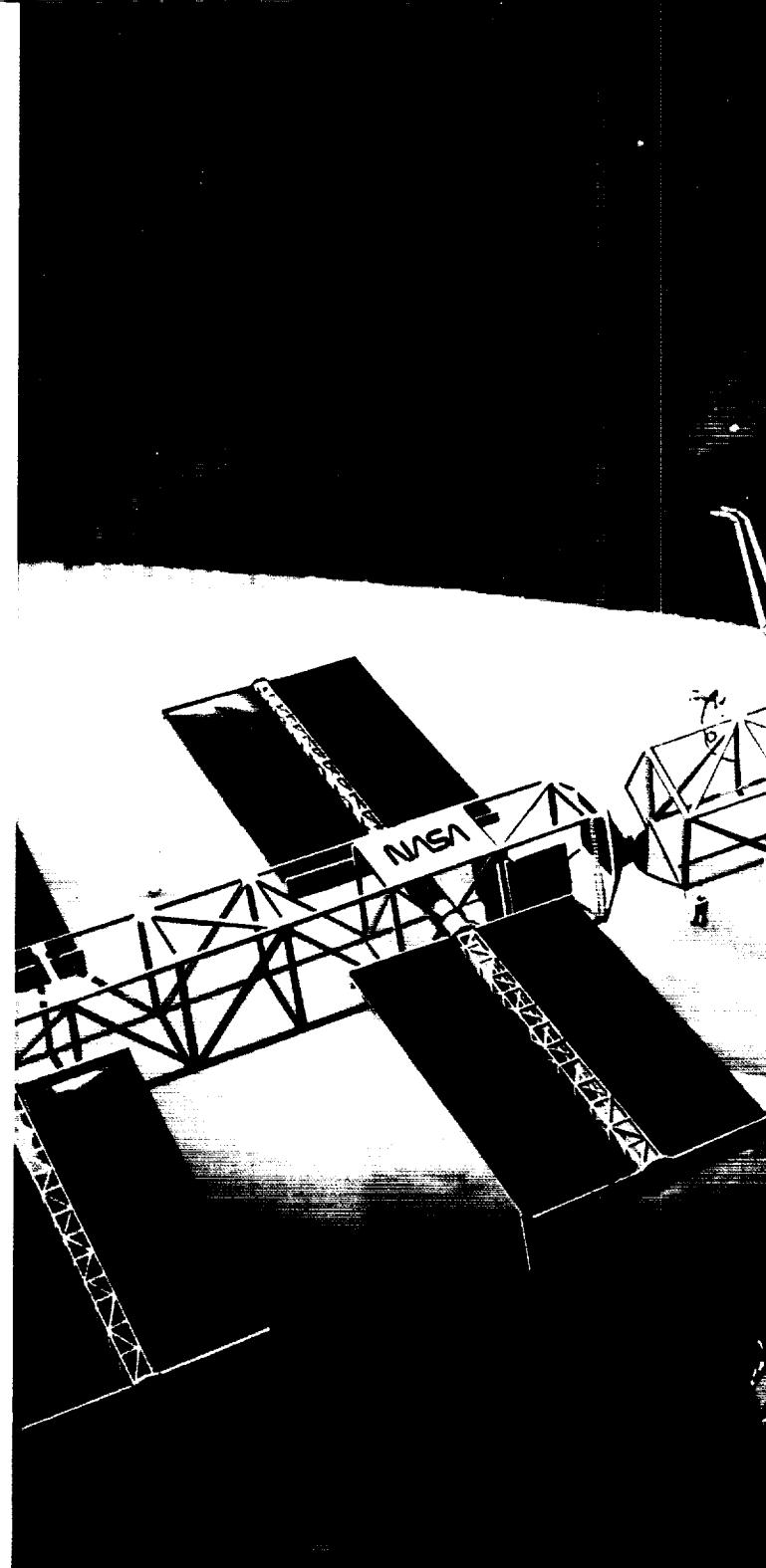
- ▶ "Space Station Freedom, this is Columbia. We are now at 250 nautical miles altitude, range 20 nautical miles. Our estimated time of arrival is 1430 hours."
- ▶ "We copy, Columbia. Please dock at Port 1."
- ▶ "Welcome aboard. After you've had time to settle in your quarters, we'll take the new scientists to the laboratory. We're processing crystals and some alloys and examining plants growing in a new habitat. We have a lot of specimens for you to take back, some blood samples and cell cultures and the latest batch of crystals and alloys."

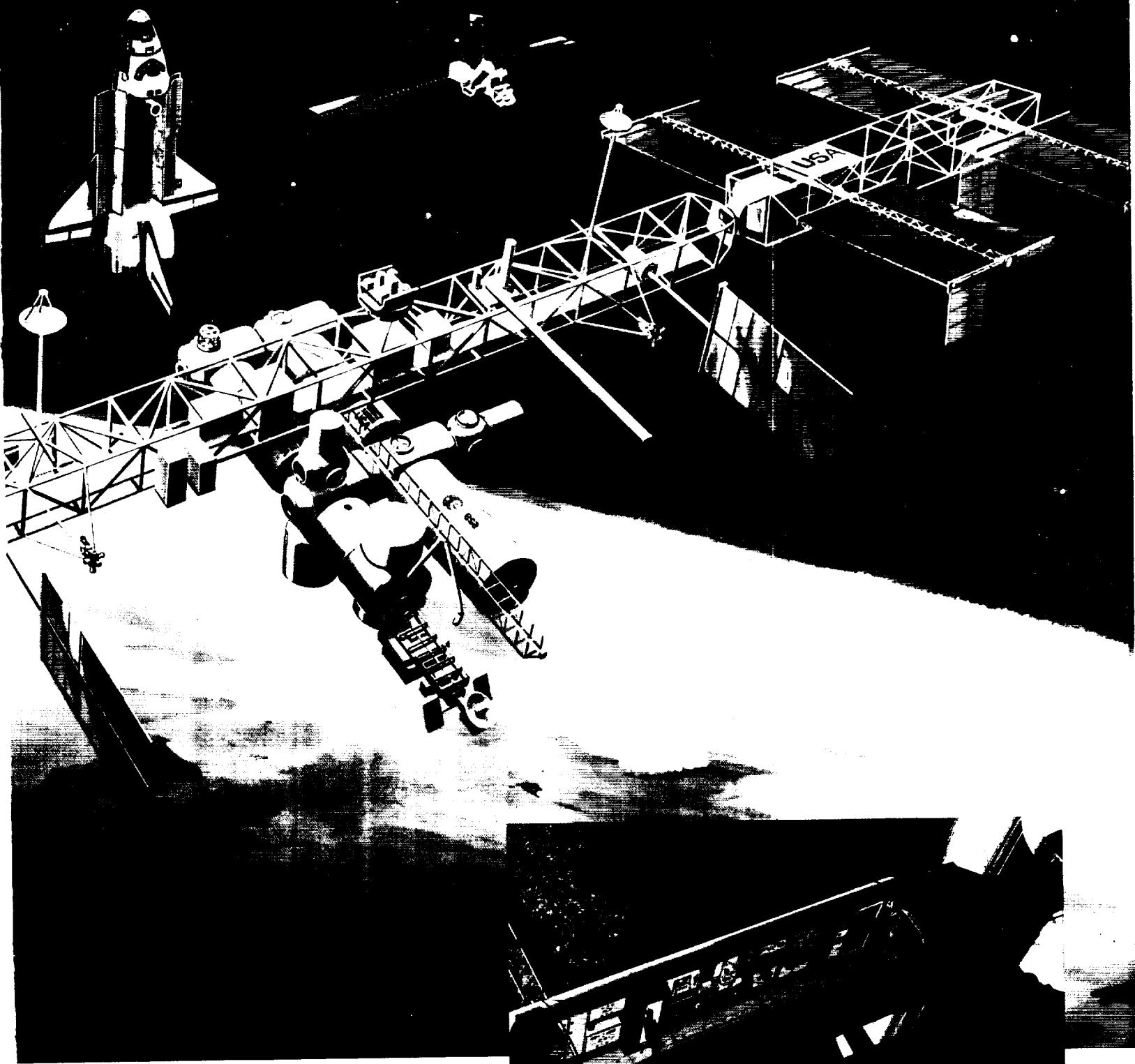
■

Before this futuristic scenario can become reality, there is much that we must learn about basic biological and materials processes. We must also learn how to work together on missions that involve the international scientific community. The First International Microgravity Laboratory mission will contribute to fundamental knowledge in these areas.

The IML-1 experiments are crucial to future space ventures, like the development of Space Station Freedom, the establishment of lunar colonies, and the exploration of other planets. On these missions, scientists from several countries will share hardware for experiments and conduct joint investigations. We must ensure that these efforts are coordinated so that everyone benefits. The success of such extended missions depends on our ability to work productively while safeguarding people, equipment, and spacecraft. To do this, we must have a thorough understanding of how biological systems and materials typically behave in space and how these behaviors differ from their usual operations on the ground.

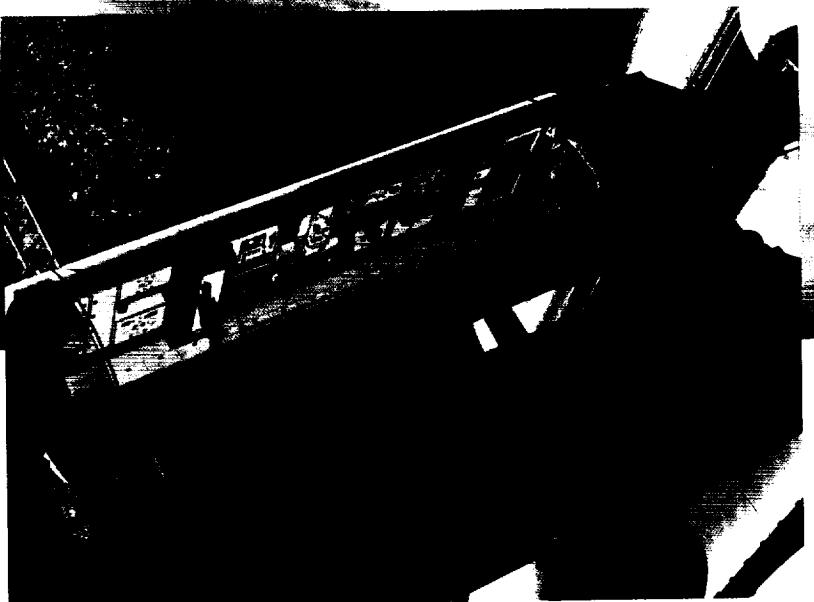
The IML-1 investigations, developed by scientists around the world, will increase our knowledge about the chemistry and physics of living and non-living matter. As we learn more about the natural laws governing our existence, we are better prepared to act in harmony with them, thus improving our ability to care for ourselves both at home on Earth and at new workplaces in space.





The United States and its international partners committed to Space Station Freedom are working together on the IML missions.

These missions are preludes to space station experiments that will take advantage of even longer materials processing times in orbit. The IML life sciences studies will also help make it safer for crews to live aboard Space Station Freedom for months.



IML-1 Life Science Investigations

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17 Phase Partitioning Experiment (PPE) Principal Investigator: Dr. Donald E. Brooks University of British Columbia Vancouver, British Columbia, Canada	26 Dosimetric Mapping Inside Biorack (DOSIMTR) Principal Investigator: Dr. G. Reitz Institute for Flight Medicine, DLR Cologne, Federal Republic of Germany
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20 Gravity Threshold (GTHRES) Principal Investigator: Dr. Allan H. Brown University of Pennsylvania Philadelphia, Pennsylvania, USA	27 Microgravitational Effects on Chromosome Behavior (YEAST) Principal Investigator: Dr. Carlo V. Bruschi United Nations International Development Organization Trieste, Italy
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 Principal Investigator: Dr. René Tixador
 National Institute of Health and Medical Research
 Toulouse, France

28 Transmission of the Gravity Stimulus in Statocyte of the Lentil Root (ROOTS)
 Principal Investigator: Dr. Gérald Perbal
 Laboratory of Cytology, Pierre and Marie Curie University,
 Paris, France

29 Genotypic Control of Graviresponse, Cell Polarity, and Morphological Development of *Arabidopsis Thaliana* in Microgravity (SHOOTs)
 Principal Investigators:
 Dr. Edmund Maher
 Open University of Scotland, Edinburgh, Scotland
 Dr. L. Greg Briarty
 University of Nottingham, Nottingham, England

29 Effect of Microgravity Environment on Cell Wall Regeneration, Cell Divisions, Growth, and Differentiation of Plants from Protoplasts (PROTO)
 Principal Investigator: Dr. Ole Rasmussen
 Institute of Molecular Biology and Plant Physiology
 University of Aarhus, Aarhus, Denmark

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 Provided by: DLR
 Principal Investigator: Dr. H. Buecker
 Institute for Flight Medicine, DLR
 Cologne, Federal Republic of Germany

31 RADIATION MONITORING CONTAINER DEVICE (RMCD)
 Provided by: NASDA
 Principal Investigator: Dr. S. Nagaoka
 National Space Development Agency of Japan
 Tokyo, Japan

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36 PROTEIN CRYSTAL GROWTH (PCG)
 Provided by: NASA
 Principal Investigator: Dr. Charles E. Bugg
 University of Alabama at Birmingham
 Birmingham, Alabama, USA

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 Principal Investigator: Dr. W. Littke
 University of Freiburg
 Freiburg, Federal Republic of Germany

39 Crystal Growth of the Electrogenic Membrane Protein Bacteriorhodopsin
 Principal Investigator: Dr. G. Wagner
 University of Giessen, Plant Biology Institute 1
 Giessen, Federal Republic of Germany

39 Crystallization of Proteins and Viruses in Microgravity by Liquid-Liquid Diffusion
 Principal Investigator: Dr. Alexander McPherson
 University of California at Riverside
 Riverside, California, USA

40 FLUIDS EXPERIMENT SYSTEM (FES)
 Provided by: NASA

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 Principal Investigator: Dr. Ravindra B. Lal
 Alabama A&M University
 Normal, Alabama, USA

42 An Optical Study of Grain Formation: Casting and Solidification Technology (CAST)
 Principal Investigator: Dr. Mary H. McCay
 University of Tennessee Space Institute
 Tullahoma, Tennessee, USA

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44 Vapor Crystal Growth Studies of Single Mercury Iodide Crystals
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 EG&G, Inc., Goleta, California, USA

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46 Mercury Iodide Nucleations and Crystal Growth in Vapor Phase
 Principal Investigator: Dr. Robert Cadoret
 University of Clermont-Ferrand
 Aubière, France

48 ORGANIC CRYSTAL GROWTH FACILITY (OCGF)
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 Principal Investigator: Dr. A. Kanbayashi
 National Space Development Agency of Japan
 Tokyo, Japan

50 CRITICAL POINT FACILITY (CPF)
 Provided by: ESA

52 Study of Density Distribution in a Near-Critical Simple Fluid
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52 Heat and Mass Transport in a Pure Fluid in the Vicinity of a Critical Point
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53 Phase Separation of an Off-Critical Binary Mixture
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53 Investigation of the Thermal Equilibration Dynamics of SF₆ Near the Liquid-Vapor Critical Point
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